Kelvin

Sustainable heating for your home

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Project: Final Bachelor Project

Squad: New Futures

TU/e

Eindhoven University of Technology

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Abbreviations

BMS	Battery Management System
CAD	Computer-Aided Design
CHESS	Connectivity in the Home with Energy, Systems, and Sound
IoT	Internet of Things
LED	Light Emitting Diode
Li-ion	Lithium-ion
MDF	Medium-Density Fibreboard
PV	Photovoltaic
SHS	Solar Home System
URE	University Racing Eindhoven

Executive Summary

Kelvin is a smart home appliance created during the course of my final bachelor's project. It explores a home battery pack for your solar panels with heating modules you can take with you through the house, providing localized heat wherever you go. The goal is to get the maximum use out of your solar panels while also minimizing the energy used for heating the home and changing the relationship people have with their energy usage. The design aims to bring back values from an old fireplace where people had to put in significant effort to heat up their homes. The report walks you through the design process with all its iterations and insights, finally exploring the final design and user evaluation.

Prologue

Last year I did a full-time board year at the student team University Racing Eindhoven. At URE we design, build and test an electric and fully autonomous racecar to compete in the formula student competitions. During my board year, I was responsible for the high-voltage battery pack as well as the driverless systems. This function made me the responsible manager for all the autonomous systems on the car, both the hardware and the software. Throughout this year I have built an entire battery pack myself and this sparked a lot of interest in me. Therefore I wanted to aim my project in this direction as it seems interesting to explore the possibilities and interactions with this in the home. I was put into the New Futures: Connectivity in the Home with Energy, Systems and Sound (CHESS) squad in which I was given the theme for energy and heat. This was perfect as this allowed me to work with and start exploring battery packs more.

Introduction

In the future, more and more households will be adopting solar panels in their homes to generate (a portion of) their electricity. As of 2023, there are many opportunities to design innovative products that can use these solar panels to their fullest extent. A known problem of solar panels however is the different times of energy production and energy use inside a typical household.

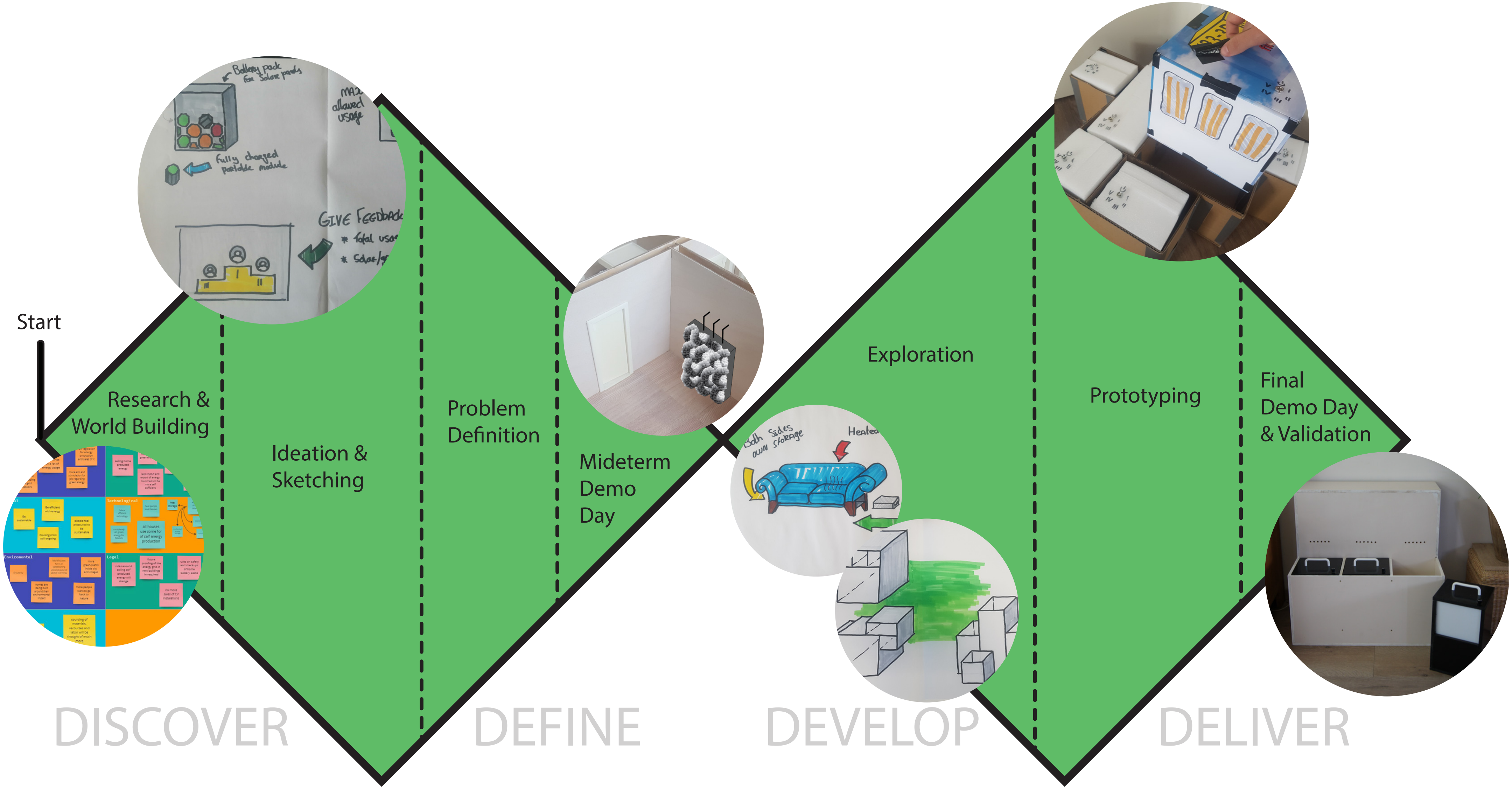
Households tend to consume the most energy in the morning and evening, while photovoltaic (PV) installations generate the most energy during midday. Consequently, the energy output of solar panels does not align with the energy demands of households (Sykes, 2019).

This means that a lot of energy generated by the solar panels does not get used by the household and gets put back into the grid. Sometimes you can get some compensation for this from your energy supplier but there are better solutions than this since the financial return doesn't match the potential savings (Zen Energy, 2023).

A solution to this problem is storing this solar-generated electricity in batteries so you can use it at a later time when the energy demand is higher and more than the solar panels can deliver. An example of this is during nighttime when there is no production but still some use of electricity albeit very little. Solar batteries enable homeowners to store excess energy, ensuring its availability for later consumption (Zen Energy, 2023). The addition of a home battery pack introduces interesting opportunities for new products and this could enhance the interaction between individuals and their energy consumption.

By adopting solar batteries in homes and leveraging stored energy during peak demand periods, households can optimize their energy usage, and maximize the benefits of their PV installations.

Project Timeline



Problem definition

Load Shifting

The main problem with solar panels in households is the overall use of the PV installation and the wasted energy not being used due to load shifting (Luthander et al., 2015). Solar panels are a great source of renewable energy which can reduce the reliance on fossil fuels. This in turn will lower the effect of climate change. The solar self-consumption of a household does not match up with the energy production of a PV system (Sykes, 2019). A solution to this is load shifting.

Load shifting is the practice of shifting the energy usage of the household, to a different period of the day. (Powerpal, 2022). When it comes down to solar panels, load shifting can take place when there is a surplus of energy being generated during peak daylight hours, but the needed energy from the appliances in the house is only very little. For example when no one is home. Consequently, the surplus energy generated by solar panels cannot be immediately utilized and is wasted.

This problem has several sides to be looked at. Firstly, the intermittent nature of sunshine and the weather makes it difficult to match supply with the variable energy demanded by a household. This means that excess energy during periods when there is much sunshine will go unused. The second part of the problem is the lack of energy storage in households to further increases the issue because surplus energy cannot be stored to be used at a later point in time when there is less/no solar generation.

The underutilization of your solar panels results in a missed opportunity to reduce your dependence on the energy grid and lower greenhouse gas emissions. As a homeowner, an investment in solar panels can be a large cost, and the subsequent underutilization of the PV installation leads to financial losses. By designing something to address this problem of wasted energy due to load shifting, you can maximize the potential of your home solar panels.

Emotional distance to energy

Back in the day, making sure there was enough warmth in your home during cold weather required much effort as the central heating system was not yet available. People relied on fireplaces as their primary source for heating their homes. To stay warm, people had to undertake a series of laborious tasks which were needed to prepare everything for a fire. They would begin sourcing and collecting logs that were suitable for firewood. Then they would chop the wood to size with an axe. The firewood had to be properly stored and dried until it was dry enough. When the time came to light a fire, careful planning was required to gather enough wood to keep the fire going for the desired duration. Once the fire was ignited, continuous attention was necessary to tend to it and ensure it remained burning to provide the warmth for which it was lit. The process of heating homes during cold times demanded considerable effort.

In comparison to the past, the present-day relationship between people and their energy has become more distant and effortless. Central heating systems allow individuals to simply adjust the thermostat to their desired temperature and their homes will be heated. This strayed away from the fireplace as now there is no physical labor involved anymore. People also don’t have to plan out their energy use anymore which was needed previously to bring enough wood inside.

The transition from firewood and putting effort in to keep a fire going has changed into effortlessly controlling your indoor temperature with a simple interface. This has disconnected people from the tangible efforts that came with heating your home. All the tasks needed for a fire provided a tangible understanding of the effort and resources that went into heating your home.

Modern heating systems also lack insight into the precise amount of energy that you consume while heating your home (Cornago, 2021). People receive warmth without thinking about the resources that go into making that heat. This disconnection from the energy consumption process can contribute to a lack of awareness and appreciation for the resources utilized.

It is important to recognize the trade-offs associated with modern conveniences and to strive for a balance between comfort and sustainability. While central heating systems offer convenience and immediate comfort, it is crucial to foster an understanding of the energy consumed. By utilizing new designs, it is possible to bridge the gap between effortless heating and a mindful approach to energy consumption.

Theoretical Framework

The sun is a powerful source of energy. Researchers suggest that the amount of sunlight that strikes the earth in an hour and a half is enough to handle the entire world's energy consumption for a full year (Khamisani, n.d.). Energy is a necessity of modern households as everything around us requires some of it. Solar panels for homes offer effective power supply solutions to generate energy (Zubi et al., 2020).

Recent advancements in Lithium Ion battery technologies allow for more favorable utilization of home battery packs (Zubi et al., 2020). A recent study for a Solar Home System (SHS) in Tanzania did a well-documented comparison between Lead acid and Li-ion batteries, showing a clear favor for Li-ion technologies (Ayeng'o et al., 2018). Dufo-López et al. (2014) compared Li-ion and lead-acid batteries, both having a capacity of 170 Wh. Despite the lower cost of lead-acid batteries ($45) compared to Li-ion batteries ($160), the study reveals that Li-ion batteries offer a 25% advantage in terms of SHS energy cost because of the longevity of the battery cells. A disadvantage of Li-ion battery packs however is the high initial investment. This can be an offputting factor for people to adopt the technology. However, recent developments show rapidly falling costs driven by accelerated market growth and economy of scale (Nykvist & Nilsson, 2015). Another big factor is the fact that there is an increasing interest in maximizing the self-consumption of PV installations through the use of Li-ion batteries (Keiner et al., 2019). The characteristics of battery packs like rapid charging and discharging are an effective method for realizing load shifting to control the fluctuations in load power (Han et al., 2015).

The biggest part of a household's energy usage is the heating of the home. Around 80% of a household's total energy usage comes from heating alone (NU.nl, 2021). Turning down the temperature by a degree will have the most impact on lowering energy usage. Localized heating systems do not replace the central heating system. Rather, the use of localized heating enables the temperature setting of the central heating system to be lowered significantly (e.g., to around 10°C) while maintaining occupant comfort (Chuah et al., 2013). Another advantage of infrared heating is that people experience more thermal comfort than conventional air-conditioning systems (Imanari et al., 1999). When comparing localized heating to programable thermostats as another form of energy-efficient heating, the savings lag that of localized heating, as well as reliance on human involvement in their operation may significantly reduce their potential savings (Chuah et al., 2013). Another part to warmth is light. Warm colored light creates a warm and cozy atmosphere and the color is soothing (Kreon, 2021). Another heating technology often used compared to infrared is ceramic heaters. When compared to infrared heaters, it can be seen that cost and energy efficiency of infrared heaters are both better than that of ceramic heaters (Home Air Guides, 2022). Not only that but infrared heaters also heat up faster and they create a quieter environment than noisy air-blowing convection heaters (Casso-Solar Technologies, n.d.).

Process

IoT Sandbox

This project was done in the New Futures: CHESS Squad. This squad concerns itself with designing for "the good life" (Frens et al., 2022). This squad employs the IoT Sandbox as a tool to help with the design process. Rather than going the route of the user-centered design approach, the IoT Sandbox offers a different route by having a fictional family: the Woo family of mundane characters living in a fictional house. These people are living in the year 2038 and they are the people we are designing for. With this Sandbox you have a better base for designing for the future every day. The IoT Sandbox is a catalyzer of insights. It is meant to make concepts of "growing systems" graspable (Frens et al., 2022). With the sandbox, you can combine designs from other projects to find new opportunities when you are designing for the smart home of the future. This was also mandated by the squad as between different project themes, data-sharing links were established. This meant that your project had to incorporate incoming data from two other themes their projects as well as an external source and find smart, clever, or interesting relations that arise when this data comes in so you could improve your design. As well as data coming in, your theme also has to send data out to two other themes their projects. Together with the rest of the squad, the characters and their activities, and the interior of the house were established during a world-building exercise. My contribution to this can be seen in appendix A. This helps to set a frame for your design and it helps you make choices during the process.

Figure 1: the IoT Sandbox (Photo Joep Frens)

Pressure Cooker

To start the design process, I began with a brainstorming session, doing a pressure cooker for myself, where some first ideas and sketches were generated. Given the theme of "Energy and Heat" that was provided, I looked into this area to explore potential design ideas and challenges. Ideas ranging from concepts like home battery packs and earning your energy to efficient heating solutions emerged. These themes were a result of initial research and spontaneous ideas. With these themes in mind, I made some initial sketches. This was so I had some materials for discussion during the first coach meeting. The objective was to get valuable feedback and guidance, allowing me to determine the most promising direction to pursue.

One of these first ideas was a modular battery pack for your solar panels where you could take out modules to bring energy with you everywhere you go. The second Idea was a sort of system that would make you input tasks or chores to earn a certain amount of energy to be used. Lastly, an interface for you to select your maximum usage of electricity from the grid and your solar home battery to try and limit your total usage.

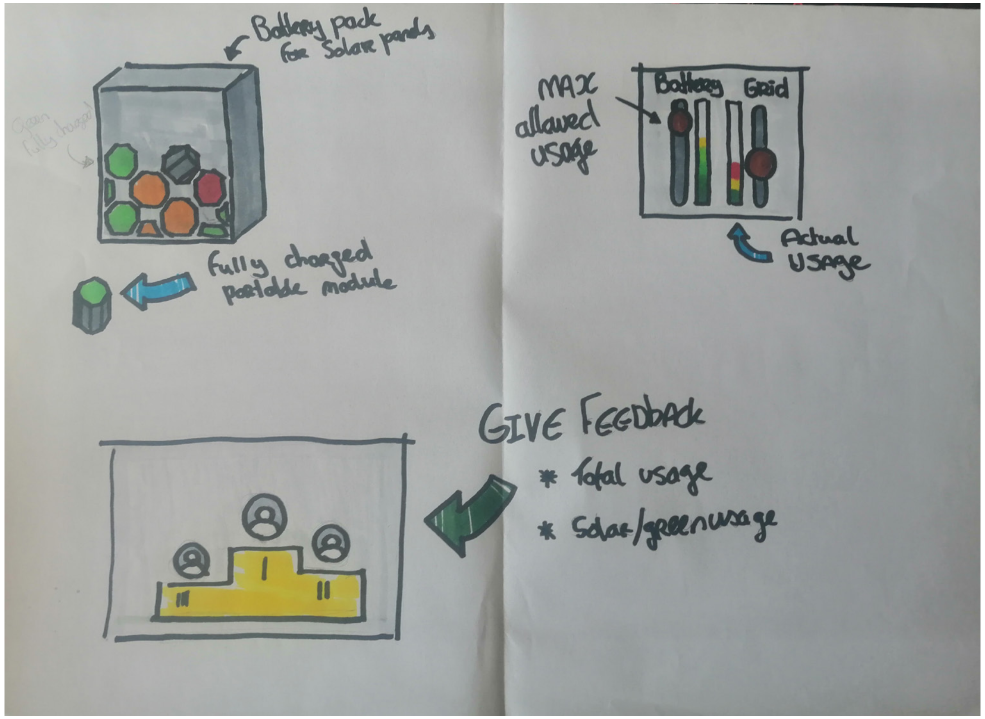


Figure 2: First sketches

These initial ideas were a good start but I was advised to take a step back and think about what the meaning of these ideas were, needing to find the abstract qualities. I knew that because of my background and knowledge, I wanted to aim my project toward the battery pack or forms of energy storage. What was the reason for me to go with battery packs?

What I find beautiful about battery packs is that they are sort of a physical embodiment of energy. Energy itself is not really visible always, but by having a battery pack you can sort of see a box of energy. Size and shape can give an indication of the amount of energy and characteristics of the battery pack. It visualizes energy in some sort of way. batteries are becoming more and more energy dense and this means that we have large amounts of energy available on the go. No plugging things into a socket in the wall. this gives people the freedom and mobility to use their electronics in places and ways not possible beforehand.

PESTLE analysis

The Woo family for which the design will be is living in the year 2038 and thus their world would look different than the one we live in right now. To build up the world of the future and describe how I envision the world of 2038, a PESTLE analysis was made to describe different aspects of how I see the future. As can be seen in the PESTLE analysis made, I suspect that in the year 2038, a lot if not all homes have some form of local energy production, as well as more of the grid being powered by green electricity. this means that there is also more storage required to make sure there will be an optimal use of clean energy. Not only that but also the rules around selling self-produced energy would probably change, meaning that you can earn money from your self-produced energy if you can store it till a time when this is energy is necessary. The key insight from the analysis is the expectation that most households will adopt some form of green energy production. This will likely be with a PV installation. Making this PESTLE analysis was important to figure out what the future would hold and if my initial ideas would even work. The analysis was made with the other FBP student in the theme of energy and heat and we both assembled the model together.

The result reinforces my decision to keep the focus on designing a battery pack. I aim to enhance the lives of the Woo family and future people by leveraging the benefits of renewable energy through the use of battery packs.

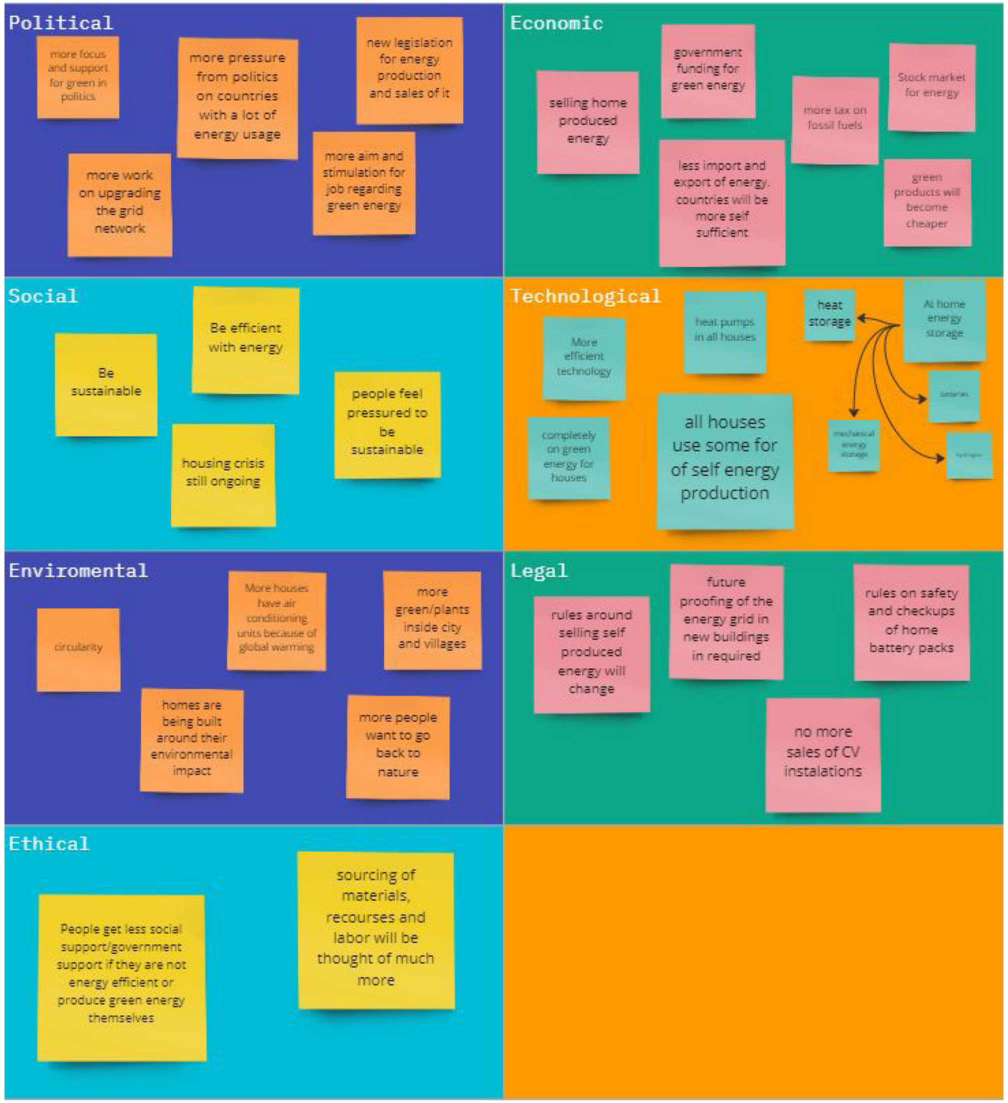


Figure 3: PESTLE analysis

Exploration of ideas and storage forms

Another theme besides batteries that kept popping up was heating and the emotional relationship people had with their energy. The comparison between a fireplace and a regular thermostat became an important part of the reasoning behind my designs. I wanted to bring back the effort that people had to put into making a fire last the entire evening, back into modern heating, or at least some of that effort. All to create a more meaningful relationship again between users and their energy.
Throughout the first couple of weeks, the designs have been focused on battery packs. However, batteries are just one form of energy storage and there are many more forms of energy storage. My first designs and ideas were all based on electrochemical batteries even though I did not have any good reasoning on why I chose this form of energy storage. The use case of my product would dictate and argue which form of energy storage would fit my design best. Instead of choosing a battery as my storage medium because I am familiar with that and I have knowledge about them, I needed to do more research on what other forms of energy storage were out there. By doing this I might find different solutions that might fit my use case better.

An exploration of energy storage forms showed many new potential forms of energy storage of which some were really interesting. Because my project was going in the direction of heating the home, it would be more logical to look into forms of heat storage. An interesting project stemming from the TU/e popped up which had great potential for my design.

Celsius is a project where heat energy is stored in a salt. Through the heating of the salt water evaporates leaving the salt dried out. When adding water back into the salt the chemical reaction emits energy in the form of heat. This closed system would have no losses and no CO_2 emissions (Cellcius, 2023). The technology is capable of heating homes without any dangers. No toxic or unsafe substances (Cellcius, 2023). This concept could fit my design as it has many appealing aspects which my design could make use of. Just like a fireplace with wood, a Celsius battery has a finite amount of energy it can store in the salt. It is a form of heat storage that is directly applicable to my project.
With the choice of technology now covered it was time to start ideating again. The main point now was how to bring back the effort in heating the home that is lost nowadays compared to the fireplace. Going exploring different areas led to ideas coming up like shape-changing interfaces where you had to 'fight' against the interface in order to get energy out of the salt battery. Another idea that found inspiration in older projects of mine using haptic feedback (Tapless, 2019) (Design and Sensorial Form, 2020). These projects used an elastic rubber band to pull and this required more force the further you pulled. This same concept would be applied as a possible idea for the salt battery. The more heat you want to have out of the battery, the harder you had to pull a lever or something to get that energy. The last exploration was worked out and it involved physically getting the energy from somewhere. Just like with a fireplace where people would often have a woodshed where the wood would be drying. They then needed to bring in enough wood for when they want to light a fire, putting in effort by gathering the wood.

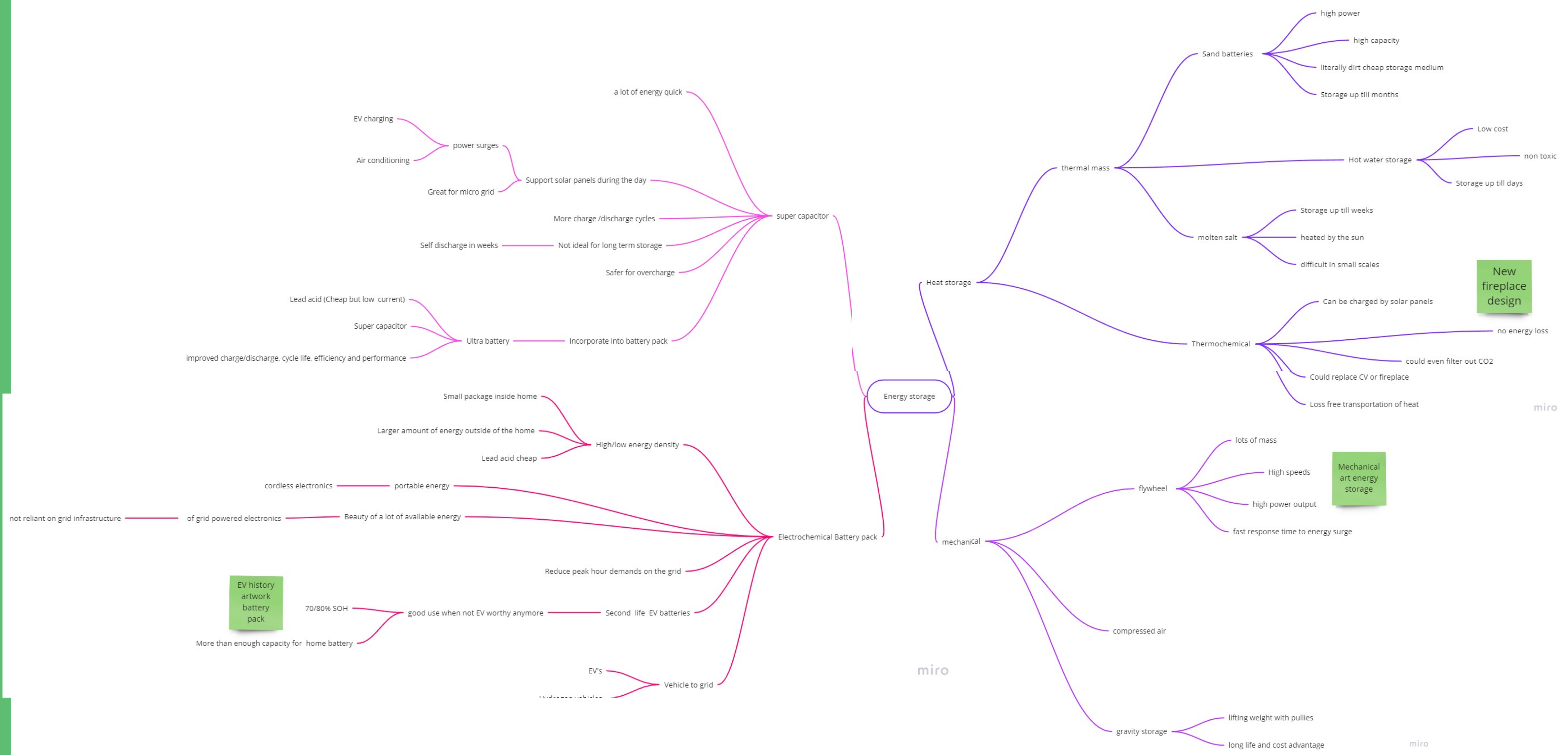


Figure 4: Explorations of energy storage forms

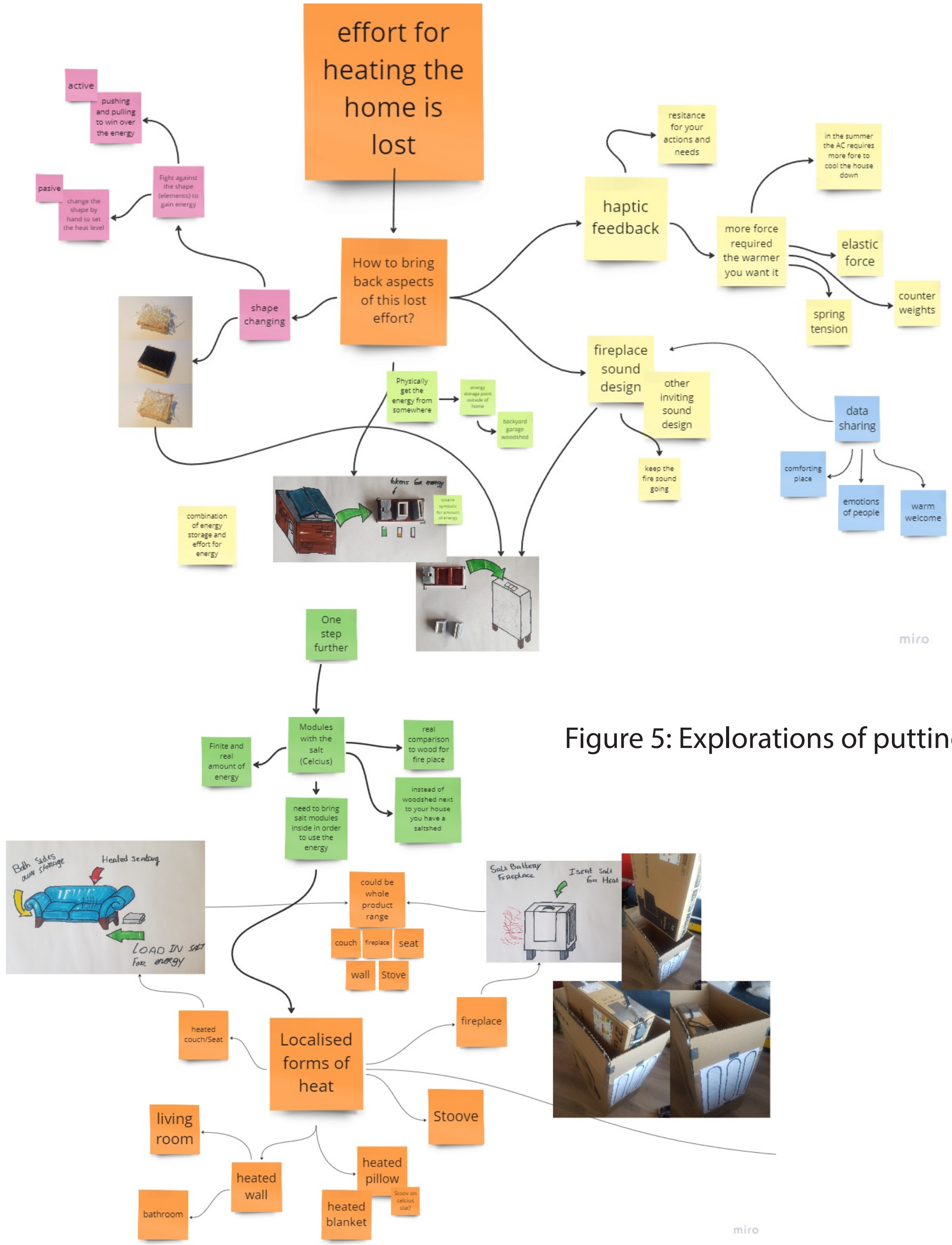


Figure 5: Explorations of putting effort back into the heating of a home

The idea of physically getting the energy from somewhere was worked out with some sketches and prototypes. The idea was that next to your solar panels outside which generate the energy to heat up the salt and evaporate the water, there would be your salt battery which held some tokens. These tokens could be gathered and would amount to some amount of energy that could be used to heat up your home. These tokens would be placed/redeemed at the installation inside your house which then would heat up your home. These tokens would be a symbol for the energy used and the effort required to get that energy would be similar to going to the woodshed and gathering wood, but then in a simpler and more modern form. The sketches and prototype can be seen below in figure 6.

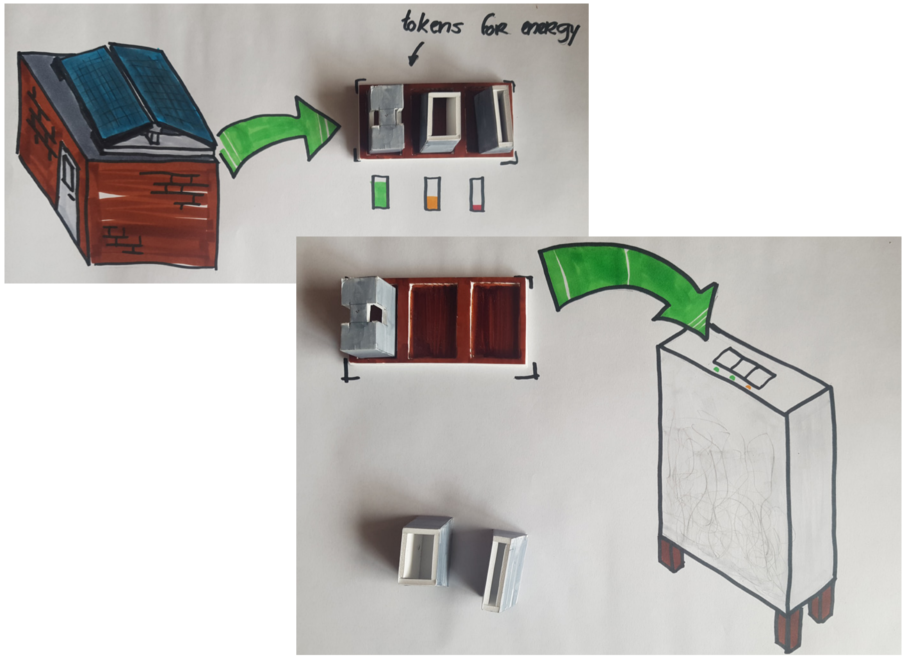


Figure 6: Sketches and prototype of tokens

After this idea, I realized I could go one step further. Instead of tokens that people could carry around, you could also have modules of the slat that can power certain appliances. Where tokens were just a symbol for the energy, these modules with salt would actually contain the energy. They would carry a finite amount of energy and I felt this would be a more direct and better comparison to the fireplace on which my design ideas are based. What products these modules would be integrated was still up for grasp but some initial ideas were created. These explorations can be seen in figure 5.

With some ideas of concepts and products made came the next coach meeting. In this meeting, my new ideas were discussed. Looking at my current concept of the slat modules we came to the conclusion that the technical feasibility would be really difficult to achieve. Even for designing 15 years into the future, problems would still arise. An installation for Celsius is currently quite large and bringing this down to a modular size that can used in appliances would not be feasible as a design. This meant that I had to either change the concept or change away from Celsius again.
Since the step from electrochemical batteries to Celsius earlier in the process, many iterations have taken place. All of them hold some value in their concept which can be extracted. There was a reason for why I decided to design that specific iteration, and I have to extract all of these important and valuable parts of each iteration and combine them in the final design. Looking back on the iterations, the modularity of the designs was a big upside as it allows users to take their energy everywhere they want to go. Having a finite amount of energy so users have to think about their energy usage. The concepts also allowed for sharing of heat between users, while having localized forms of heating. Carrying around modules or tokens still required some form of effort to be put in for receiving some energy. All these aspects are really important and need to be brought over to the new design.

Because the use of Celcius technology would not be feasible, I went back to electrochemical battery storage as this would still work with all of the values set by previous iterations, while also providing a base for which the design would be technically feasible. This led to the predecessor of the final design. A home battery pack with modules of different sizing all carrying heaters. These would provide localized forms of heat which could also be shared between people. These modules would run on their own batteries which all have a finite amount of energy that people can use before they need to be recharged or swapped out with a new module. This battery would be a great addition to the solar panels as it offers great options for load shifting with the solar panels. The elegance of the design would not be feasible through the use of the Celcius technology but it will be by using electrochemical batteries.

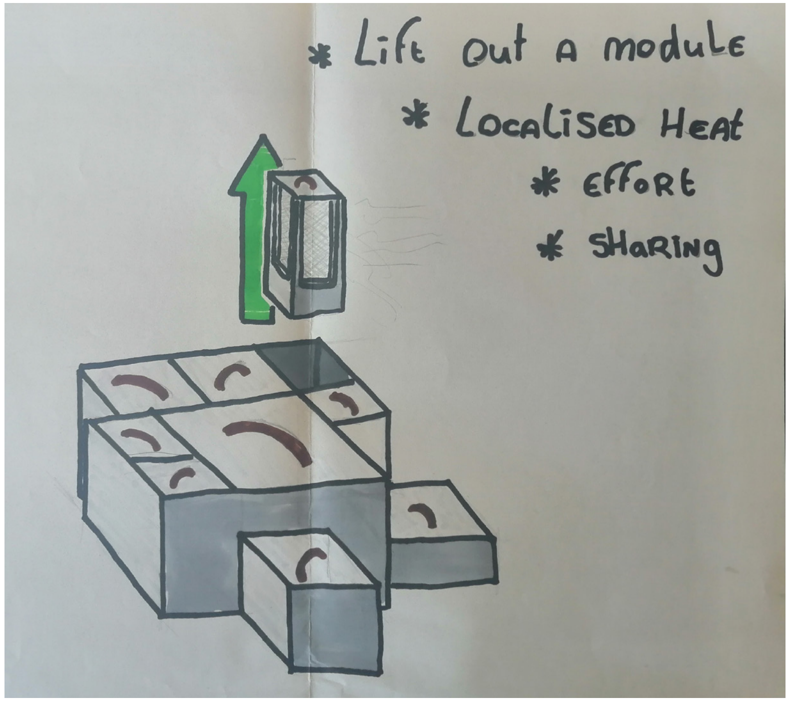


Figure 7: Sketch and prototype of the battery pack with heating modules

With the prototype made from cardboard and some tape, feedback on the design could be gathered to make the final design and make it come to life. One of the points was that for a normal sized family, 7 heating modules would be a bit much and the design could do with fewer modules that are slightly bigger. Another great point of feedback was the inclusion of a normal battery that could power your electronic appliances as well. A combination of electrical storage as well as a couple of portable heating modules would be the best solution for a convenient home battery pack.

Final design

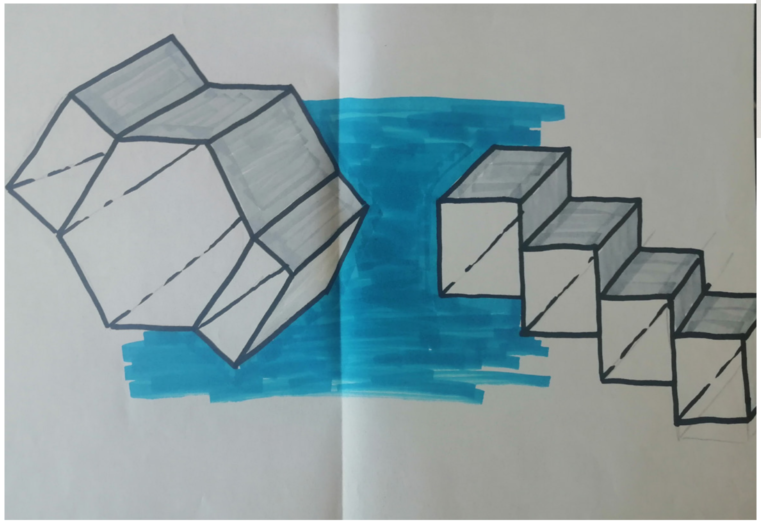
Kelvin is a home battery pack for solar-powered heating.
It is designed to maximize the energy usage of your solar panels while providing a new heating solution. It transforms the way you warm yourself inside your home.
Conventional heating methods are responsible for roughly 80% of household energy usage (NU.nl, 2021). Kelvin addresses this problem by offering three portable heating modules that utilize infrared heating panels. By using infrared radiation, Kelvin provides localized heating, directing warmth directly onto your body instead of heating the surrounding air around you. This method not only offers greater efficiency but also delivers a more comfortable and enjoyable heating experience.
The flexibility of Kelvin allows you to take the warmth wherever you go, both inside and outside your home. The portable heating modules provide a convenient heating solution that adapts to the user's needs. No longer bound by fixed heating systems, Kelvin allows you to create a comfortable environment anywhere you go.
By using battery power, the heating modules encourage users to become more conscious of their energy consumption. With a finite amount of energy stored, users develop a heightened awareness of the energy they use.
Furthermore, the warm light emitted by the heating modules adds to an ambiance and coziness to your surroundings. This warm illumination enhances the overall experience, making the user feel more comfortable.
With Kelvin, you can optimize the use of your solar panels and enjoy the comforts of efficient and localized heating. Kelvin improves the way people stay warm while reducing their carbon footprint

Placement in the home

The concept behind Kelvin is to position it as a central piece in your living room, similar to a fireplace. The design allows people to gather around it or use it as a display surface for a picture frame or plant. Just like you would with an old fireplace with a mantle. The design aesthetics were carefully considered to seamlessly blend with modern house interiors, featuring colors that complement white and neutral bases commonly found on plastered walls. The modules themselves have a black housing with a white infrared panel for the heating.

Size/shape

To find the shape of kelvin, some sketches were made looking at the aesthetics as well as the packaging of the design. The shape of Kelvin was chosen to have optimal packaging to fit in enough battery capacity Having a square and rectangular body allows for optimal packaging of all the components required to fit inside of the enclosure as well as inside of the heating modules.



The final design was then drawn into CAD software to get a better grasp of the sizes and fitment, also taking into account the producibility of the prototype. The back side of the housing is where the battery and other electronics are housed and this has a size of 600x600x200mm. The front where the modules are housed has a size of 300x600x200mm. The modules themselves have a size of 300x180x190mm. The design also has two different modules. Two with a single heating panel for direct heating in one direction, and one module with two heaters for a wider range of heating, where people could more easily share the heat of a module.

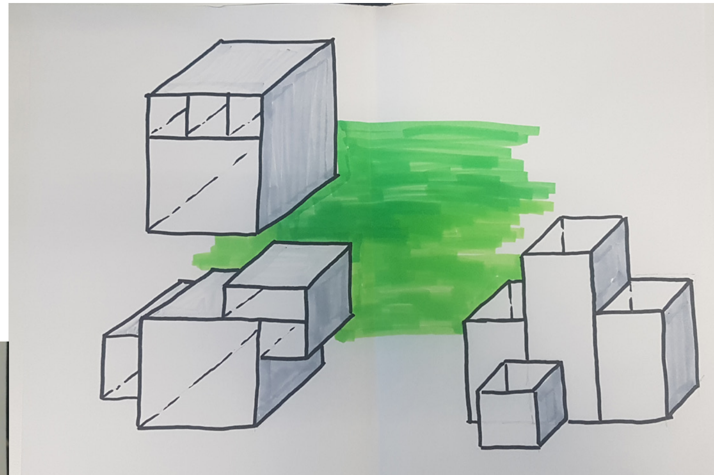


Figure 8: Form explorations of Kelvin

Figure 9: 3D renders of Kelvin

Amount of modules

To choose how many heating modules Klevin has, some research was done into the average household composition. Most of the Western world has fewer than three people living in a single household on average according to research from the united nations (“Household Size and Composition Around the World,” 2017). Therefore it was chosen to have three modules as this meant that there would be at least one module for each person in the household. A consideration could be made to have Kelvin be customizable or upgradeable to include more modules if the users live in a bigger household.

Capacity of the battery and modules

To know what the capacity of Kelvin should roughly be w we first need to know the average electricity use of a household. According to the Nibud, an average household of 3 people uses 3.430 kWh a year. This comes down to roughly 9,3 kWh per day (Kosten Van Energie En Water | Nibud, 2023). This will also be the goal of the total capacity for the battery of Kelvin. Inside the housing of Kelvin, a lot of parts need to be placed in order to have a functional product. To make sure everything is considered, a product breakdown structure was made.

As can be seen in the product breakdown structure, next to the cells that hold the actual energy, a lot of other components are needed for a working infrastructure. As it is difficult to know the exact dimensions of all of these needed components, a rough estimation was done based on personal knowledge and experience. Most of the space in the back of the design will be allocated to all the electronics and only roughly a third will be available for the actual battery cells, which will be 200x600x200mm.

The paper from Zubi et al. (2020) explores many different types of cells of different types of chemistry, size, and capacity. Choosing a cell from this paper is difficult as there are many stated in the paper, but they also mention these are just e few of many cells out there. Therefore I chose a cell on which I have more information. The datasheet can be found in appendix B. This was a possible cell for the battery pack of the URE car but ultimately fell through as it could not deliver enough current for the car. This would not be an issue for Kelvin as the total amount of cells in series would be lower due to the lower total voltage of kelvin compared to the 600V URE battery pack. In addition, there would also be more space to put cells in parallel for extra output current This means in the available space more cells can be placed in parallel providing sufficient current for a household. The cell is an INR-21700-P42A and it is a cylindrical cell with a diameter of 21,7mm and a height of 70.2mm. Taking into account all the mounting, connections, and wiring, a rough estimate of around 620 cells can be placed in the battery design. This will give the battery a capacity of 9.67 kWh which will be sufficient for the goal set of the total capacity.

The heating modules also run on an internal battery which needs to power the heaters. The heating modules have a size of 180x190x300mm and the estimated guess would be roughly half of that would be available for the battery cells. This would amount to roughly 98 cells and 1,52 kWh of capacity for each module.

Product breakdown structure

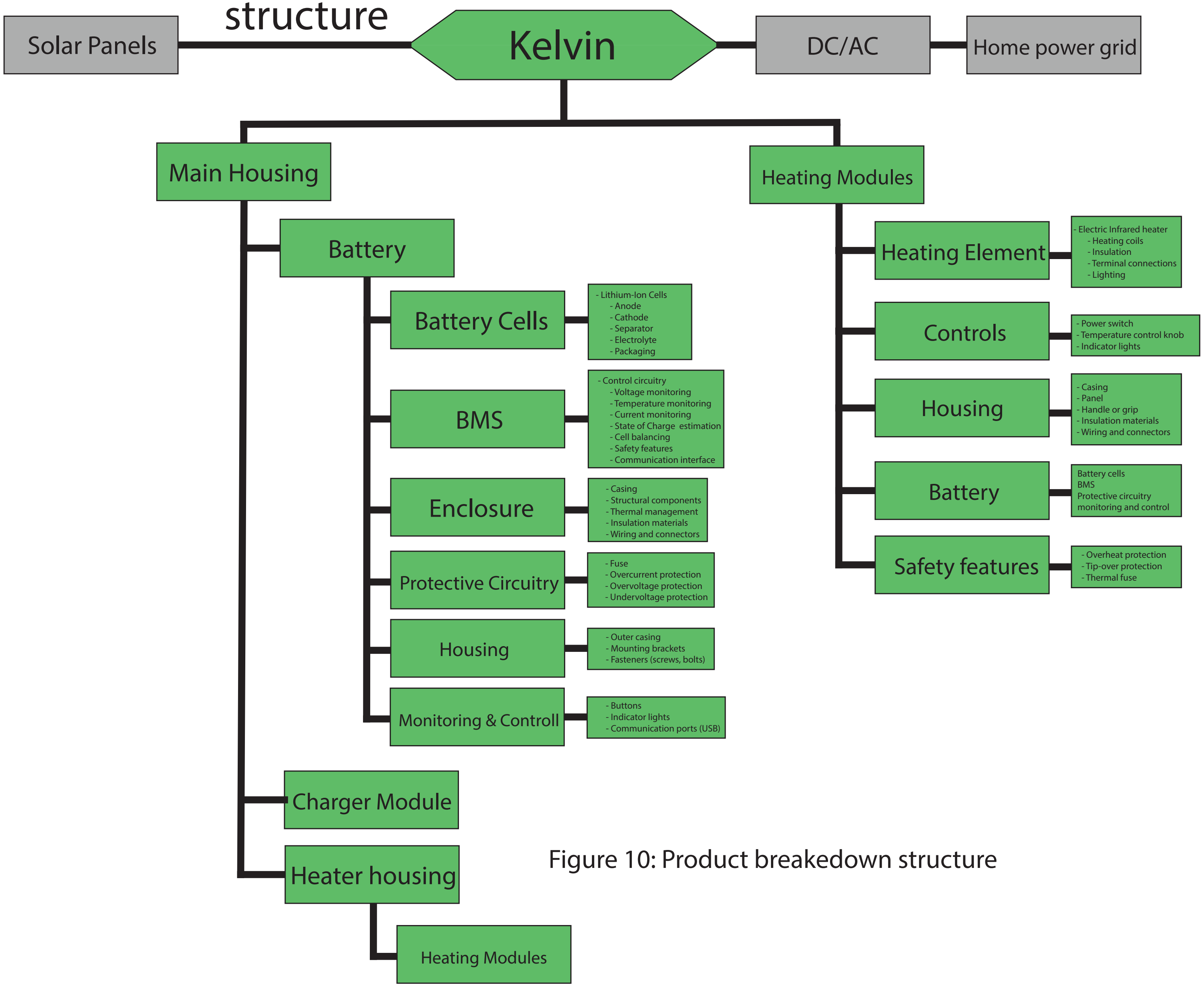


Figure 10: Product breakedown structure

Duration of heating per module

One thing that is really important for the concept is how long a module could deliver heat to the user. If it would only last 10 minutes then it would be a flawed design. Assuming the voltage on which the modulus runs is a 24V low voltage system as this is safer and easier to implement than a high voltage system, the total Ah of the battery in a module can be calculated. 1.52kWh ÷ 24V × 1000 = 63 amp hours of battery life. Choosing an infrared heater of 250W which was also done by Chuah et al. (2013), you can calculate the amps the heater uses as 250W/24V = 10A. Combing the total capacity with the usage of an infrared heater calculation can be done on how long a heater would last on a full charge. The battery life would be equal to the capacity/load current. 63Ah/10A = 6 hours and 18 minutes of battery life which. Knowing that other electronics like the BMS and the LEDs inside would also use some power, a battery life of 6 hours for a module with one heater would be possible. This would be sufficient heating for a person on a long evening. A module with two heaters would thus have a battery life of 3 hours roughly which is significantly less but on the lower limit of acceptable.

Light and infrared panels

Having both the infrared panel as well as lighting element implies some thinking on the implementation. Placing something directly in front of an infrared panel is not really possible so the design will consist of a white opaque thermo glass infrared heater. Behind this there will be LEDs for the lighting, offering smooth and soft lighting through the opaque glass. This would probably be slightly more expensive than a simple infrared heating panel but that would not allow for the lights to shine through. The lighting itself will be animated so the user can see it move just like a fire. It aims to be the same as a fire inside a fireplace where you can gaze into it.

Inside the smart home of the future, there are many different appliances all working together. Kelvin itself has many sensors and points of data coming in but other smart home appliances share data on the network as well. For kelvin itself, it is obviously important to know at first if there is more energy being generated from the solar panels than there is being used. If this is the case, Kelvin will start charging. Because Kelvin has a main battery as well as three modules which all need to be charged, Kelvin needs to approach this in a smart way. A good way to start is to measure the temperature inside the house to know if it is important to charge the battery or the modules first. If it is summer and 22C inside the house, there is no need to put priority on changing the modules. The opposite would be true for the winter. When heating is needed but only a little bit, Klevin can also decide not to fully charge the module before switching to charging the battery, switching to the modules again when it is sufficiently charged. But temperatures inside the house do not stay stationary, they fluctuate depending on the weather outside. Therefore Kelvin also looks at the weather data and weather predictions. If a cold and rainy evening is predicted, Kelvin needs to prepare for this during the day when the solar panels are still delivering power, so when it is dark and rainy the user has a nice place to warm up.

In the smart home, every appliance is connected and communicates with each other. This meant that incoming data from other appliances from the CHESS squad had to be incorporated into the design. One of these projects was Greetme (van Gompel, M., 2022). This project greets people when they enter the house and share information about who is home and when people are coming home. The last part is especially important as this indication allows Kelvin to prepare charging the modules, making sure the user can find a sufficiently charged module upon arriving home.

Another project Kelvin is receiving data from is Comfort Hub (Koonings, N. 2022). This product allows the user to input how he/she feels, so the smart home can respond to that. Changing the lighting, sound, and scent based on the emotional needs of the user. Kelvin can also join this by ensuring the user can have a sufficiently charged module whenever he/she needs a little bit of extra warmth to comfort and relax them.

Kelvin is not only receiving data but it also needs to communicate outwards with other devices. The main way Klevin does this is by sharing when extra energy is available. Not all appliances/products need electricity all the time. Some just require momentary access to some power if they have a way to store some themselves. Kelvin communicates with the rest of the smart home when the solar panels are delivering ample energy and one or multiple modules are in use for example, meaning they are being carried around and can't be charged currently. Kelvin has no place to put this surplus of energy so it communicates to the rest that now might be the best time to use this surplus electricity. Clearly scheduling when each appliance uses the energy so they don't conflict with each other and the energy from the solar panels gets used to its fullest potential.

Of course, the user itself also has control of the charging algorithm with a supported app allowing them to change the charging rates and priorities to their desired wishes.

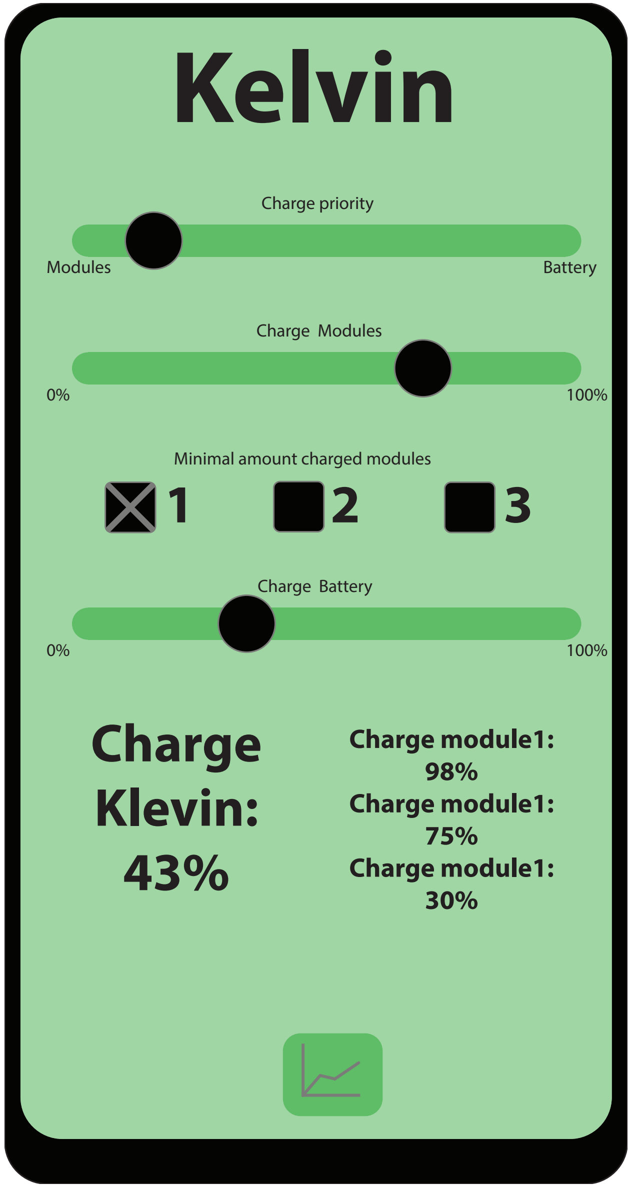


Figure 11: Interface of the app

Social Context

The social context of Kelvin within a household revolves around the benefits it brings to the users and their daily lives. Kelvin promotes an energy-conscious lifestyle by encouraging users to be thoughtful of their energy usage and also cooperate with each other on the energy usage of the day. The portable nature of Kelvin's heating modules allows users to adapt to various spaces within their homes. It enables individuals to create a comfortable environment wherever they go. Kelvin, as a central piece in the living room, or one of the modules encourages gathering around and sharing experiences and warmth with each other. Sharing heat can foster social interactions and create a cozy ambiance for conversations. Kelvin's social context within a household revolves around sustainability, personalized comfort, flexibility, and shared experiences.

Final Demonstrator

For the final demo day, a demonstrator prototype was made to showcase the concept of Kelvin to a bigger audience. The prototype was made of MDF wood and electronics powered by multiple Arduinos. The wooden parts were sawed to size, painted, and bolted together.
The prototype contains two Arduinos, one in the main housing and one powering a single module. In the main housing, there are three LED strips for indicating the charge level of each of the modules. There are also three optical distance sensors to turn on/off the LED strips once a module is placed or removed from the housing. The Arduino in the module has a potentiometer to turn on/off the LED strip for the orange lighting. The Arduino in the main housing was also connected to a laptop running a processing script. This was to have the working data sharing via OOCSI. OOCSI is a prototyping middleware for designing distributed products (Funk, 2019).

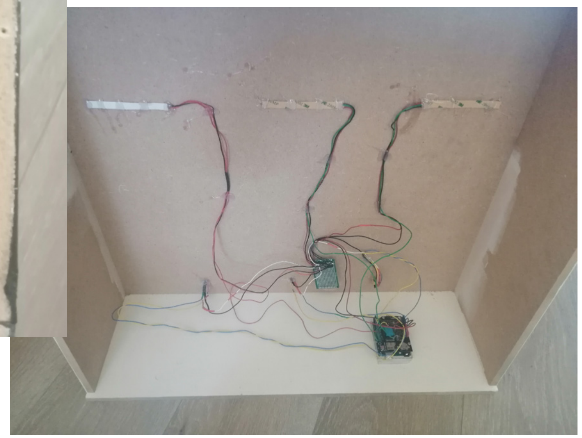
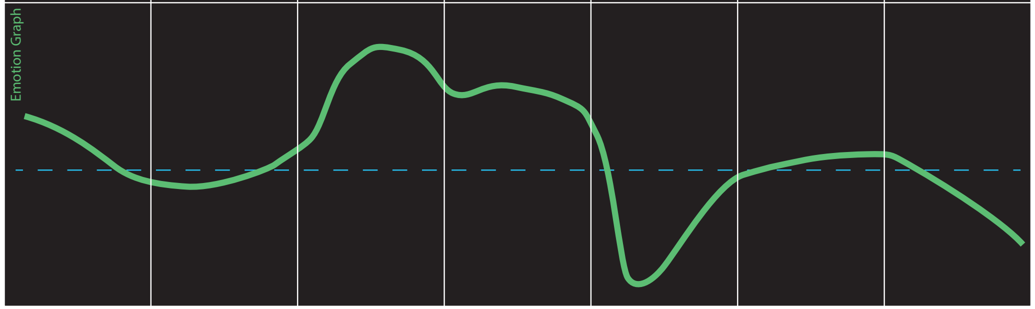


Figure 12: Final demonstrator

To understand the user better A customer journey map was made. It aids in comprehending and enhancing the total client experience. It identifies problem areas, raises satisfaction, improves touchpoints, and increases engagement. As can be seen, the user would not feel happy when a battery is empty. However, this would also ensure the users will think about their energy usage better as they don't want to end up in the same situation as before. Next to this, a sustainable business model canvas was made to check if its core principles and ideas of Kelvin would ensure long-term viability while minimizing the negative impacts. Lastly, a SWOT analysis was made to capitalize on the strengths of Kelvin to emphasize these, while also addressing its weaknesses to find areas of improvement. By also looking for opportunities, Klevin can evolve and be one step ahead in future iterations. It is also important to find solutions to mitigate threats that could arise. It is important to understand the current position to know what can be improved and what areas should be paid extra attention to in future steps to improve the design. The results of the business models together with the results of the user evaluation will be explained further in the discussion.

	Exploring	Purchase	Instalation	Use	Empty Battery	Charging	End of life
Emotions and thoughts	Wow this looks like an intresting home battery pack for my solar panels Curious	It is expensive but worth the money Worried but happy	Yessss finaly it is here, let's get it installed Exited and happy	Having these small heaters gives some cofortable heat wherever I go Satisfied	I have got to be morecarefull with my energy use, now it's getting cold quite fast Annoyed	It's time to charge the module again. the sun is shining bright so there is plenty of energy available Calm and Understanding	Unfirtunately it's just not what is used to be anymore Sad and concious
Touchpoints	Lands on website, sees advertisements online. Reads reviews online. Goes to a dealer to get more information	Compares the battery with competitors. Check for additional accessories like instalation and delivery	Package gets deliverd and installed. Long process of instalation but almost ready for use	Electrical batteries mostly opperant on the background	Making sure you plan out how much energy you have, so you know how much heating you can use	Realization that there is no infinte heating/energy, and it costs something to get that energy	After many years of apperation the battery needs replacement. It will remain a question how much of the battery can be recycled again

Emotion Graph



Strenghts	Weaknesses
- Maximize solar panel use - Localised Heat - Sharing of Heat - Creating Awareness - Lowering monthly costs	- Expensive to buy - dependant on having solar panels - Battery lifetime
opportinuties	**Threats**
- Growing market for sustainable heating - Expansion into new markets - Advancements in battery technologies	- Competative market for heating - Regulatory and policy changes - Economic buying power of people

Positive Impact (Maximise)

The utilization of all energy provided by the solar panels, and lowering the need for your central heating system

Negative Impact (Minimise)

Minimize the use of grid power to save money and use of unsustainably generated electricity, as well as lowering gas useage

Sustainable Partners

The production process can be localised more. More smaller production plants more local to the area of use. This would lower shipping polution

Sustainable Value Creation

Maximise the use of your solar panels

Sustainable Tech & Resources

Technologies for circular economy

Sustainable Value Proposition

Value: Use all the power generated by your solar panels, and deliver localsied heating in your home

Sustainable Customer Relation

Customers who care about sustainabilty and design can now be heated by Kelvin

Sust. Channels

Aim to have more and more houses implement Klevin to maximise their returns from their solar panels

Responsible customers

Customers who have solar panels and want to make the most of it

End of Life

At the end of the product life it is waste with limited options to recycle

Cost Structure & Additional Costs

Customers would buy Kelvin and after that they would start seeing the benifts of that on ther energy bill

Subsidisation

customers could recieve small aditional funding from the government for this purchase

Revenue & Sustainability Premium

Customers who care about sustainabilty would pay for the big upfront pricce of a batery pack and will see the returns of longtime use

Evaluation

Method

With the final design finished and a demonstrator built, a final user evaluation study will be done to find out points of improvement for the final design, as well as find out the general user experience with the final design. The questions to find out the points of improvement will mainly be aimed towards the general user experience, and if people see the value of the fireplace back in the design. To evaluate the user experience, a user test was done based on a heuristic evaluation (Nielsen & Molich, 1990). Based on Nielsen (1994) the user test was prepared.

Heuristic evaluation is a method where individual users independently inspect the design before sharing their thoughts. When users encounter issues or require an explanation of some aspects of the design, the researcher may be able to help them out by giving some brief explanations. In contrast to conventional user testing, heuristic evaluation encourages users to ask questions about the design being tested and receive responses from the researcher. When having trouble with the design, users can also get hints. Users are allowed to decide how they want to evaluate the design however, it is advised that they do so at least twice. Heuristic evaluation results in a list of usability issues that can be used as the foundation for a new design.

Setup

The users were given the prototype and a basic explanation of its capabilities and functions. Then the participants were asked to interact with the design through different routines. First, they were asked to just interact with the design in any way they liked. After that, they were given some scenarios to help them think about how they would use the design differently (appendix C). After these scenarios were played out, a general discussion with the researcher takes place on their findings, also giving more explanation about the design and the ideas behind it.

In total 3 participants were chosen to do the final evaluation all of them were selected to participate because of their affiliation with a fireplace of some sort. Two of them have a fireplace inside their home and one with a fireplace outside. One of them also has solar panels at home. Each session took around 30-45 minutes.

Results

The observations and the interview were required to be transcribed in order to examine the qualitative data that was gathered during the observation and the interview. Any insightful comments on the design might then be recorded within the transcription and categorized using different color schemes. Composing these several groupings as you reviewed the findings was already a sign of areas that needed improvement or plus points of the design. The grouping of the participants' various statements provided more clarity as to what specifically needed to be improved.

The groupings indicate some areas that people had comments on, either good or bad. The results of these groupings can be seen in figure 13. As can be seen, there were some recurring themes that came up during the answers.

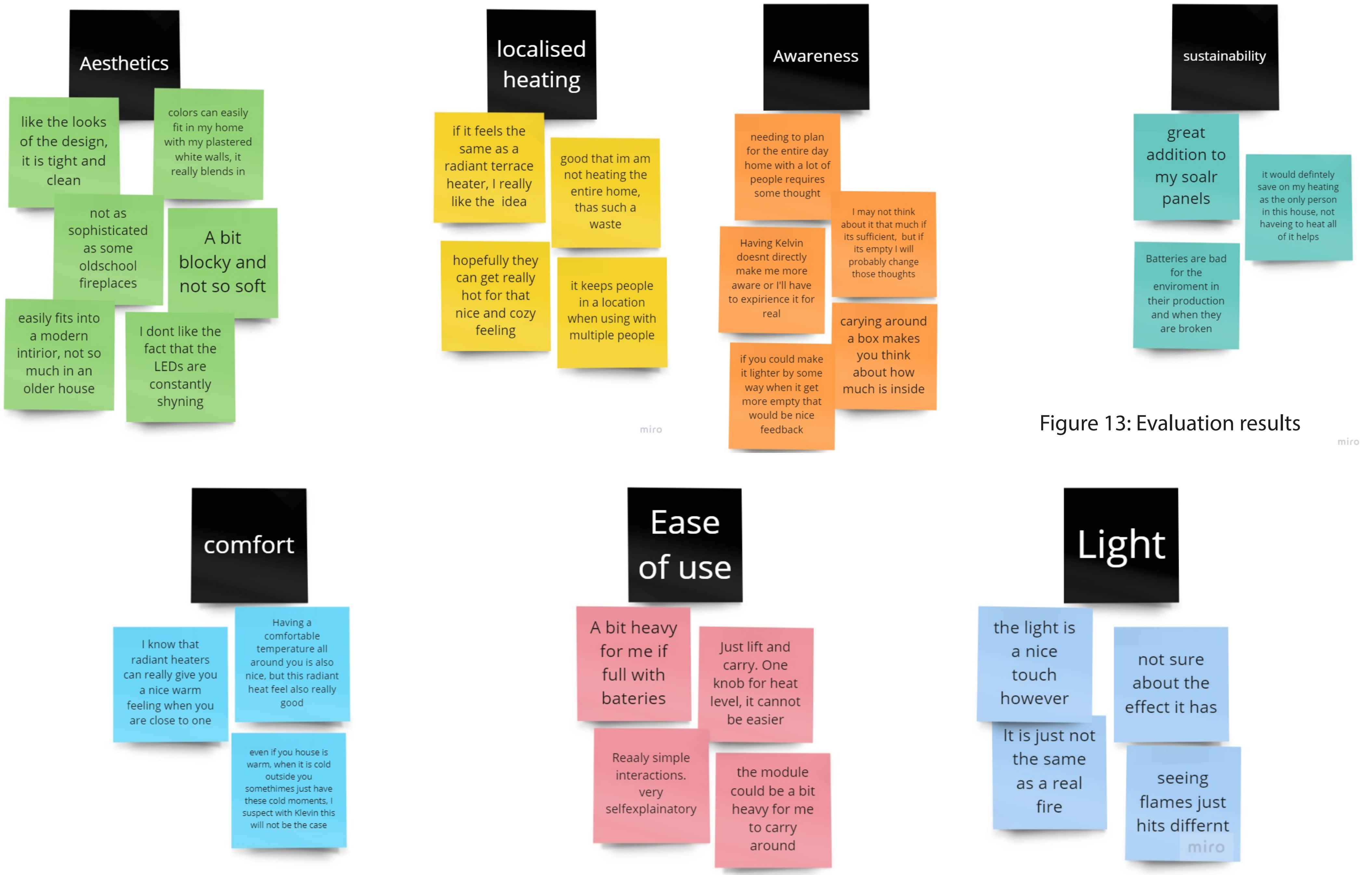


Figure 13: Evaluation results

Discussion

As can be seen in the results from the final user evaluation, there are still some points of improvement for the design. One overarching theme though was that some aspects of the design were difficult to test with the prototype, mainly the heating part of the design. This was one of the shortcomings of the design and future work on this project would definitely involve a working infrared heater to test with. As for other pain points of the design. One of the participants was an elderly woman and she indicated that a module full of batteries could be a bit heavy to carry for her. This is a fair point and one of the features is not really able to be changed. This weight problem would also hamper children to use the design but these can be assisted by parents whereas elderly people not always are able to be helped. Another thing that popped up with the user evaluation as well as with the sustainable business model canvas is the fact that the production of batteries is not that sustainable and is also a bit unethical (Amnesty International, 2021). So a participant had some doubt about the sustainable impact the design truly has. The warm light the modules emit as well was also doubted by the participants. Further research will have to be done to truly find the impact of the warm orange light on the feeling of warmth and coziness to the user. As for some positives that came out of the final evaluation. The aesthetics were a bit based on personal opinion but the design aimed for a modern look and several participants confirmed this by saying it might fit in their house quite well. The participants did understand the feeling of localized heat from their fireplace or a terrace heater and could imagine the modules doing the same. They felt this form of warmth as a comfortable and enjoyable warmth. The one participant who had solar panels themselves also believed it would be a great addition to their house as they regularly see the electricity meter run backward, wasting solar energy. The modules themselves are also really easy to use as it is just carrying them around and turning them on to a certain heat level.

Conclusion

Kelvin is created to improve the sustainability of a household by making optimal use of their solar panels and making use of localized heating. Research has shown that localized heat is an efficient way to reduce energy usage in buildings (Chuah et al., 2013). Having the heating modules of Kelvin allows for this thus lowering the energy use of the household. By having these heating modules, Kelvin offers a unique combination of localized heating powered by the solar panels of the household. The design also recognizes the shortcomings in the prototype and the ability to test certain aspects of the design however, the opportunities presented by the increasing amount of solar panels being placed allow for a great impact on the world of 2038. Through the user test, insights were gained on the next steps of the project.

Overall this report shows the viability and potential of Klevin as a smart home appliance, heating the homes of the future. Its ability to optimize solar panel usage, provide efficient heating and offer flexibility positions Kelvin as a significant contributor to sustainable living and a step towards a greener future.

Acknowledgments

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Appendix

A) World builing

Entertainment Manifestation 2038

VR Meditation and relaxation

In the everyday world where everything is becoming more busy and busy every day. It is hard to find a place to relax and calm down. Even in your own home, there are often too many distractions or stimuli to fully immerse yourself in meditation or relaxation. VR can give an escape to a different realm. One the user sets and finds relaxing or beautiful. Get immersed in a world of beautiful nature with amazing views and lovely sounds. Fully come to rest in this peaceful place and have a moment for yourself.

Hologram sculpting

People are eager to practice forms of art to express themselves. With the advancements we have moved away from a blank canvas, working in only two dimensions. Now we people are able to express themselves easily in 3D. No need for materials which only can be used for one project. With hologram sculpting, people can create beautiful forms of arts while fully expressing themselves with all of their bodies. Become fully emerged into the art you create by using all of your body to create and experience the art you make.

Human vs AI in sports

What better than spending some time in the weekends than watching your favourite sports team? It is a good way to relax or experience some joy. But what is a better way to experience the top of human abilities in these sports? Match them again with AI to see which is better. Human versus machine sports is becoming more and more popular. For now, the top performing Human vs machine sports is Formula-EAI, FootbalAI and AI-Athletics. Although other sports are becoming more and more popular, these are currently attracting the most views

B) Cell data sheet

MOLICEL®

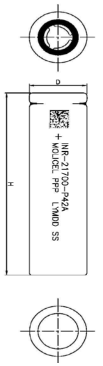
LITHIUM-ION RECHARGEABLE BATTERY

PRODUCT DATA SHEET
MODEL INR-21700-P42A

■ CELL CHARACTERISTICS

Capacity	Typical	4200 mAh 15.5 Wh
	Minimum	4000 mAh 14.7 Wh
Cell Voltage	Nominal	3.6 V
	Charge	4.2 V
	Discharge	2.5 V
Charge Current	Standard	4.2 A
Charge Time	Standard	1.5 hr
Discharge Current	Continuous	45 A
Typical Impedance	AC (1 KHz)	10 mΩ
	DC (10A/1s)	16 mΩ
Temperature	Charge	0°C to 45°C
	Discharge	-40°C to 60°C
Energy Density	Volumetric	615 Wh/l
	Gravimetric	230 Wh/kg

■ PHYSICAL CHARACTERISTICS

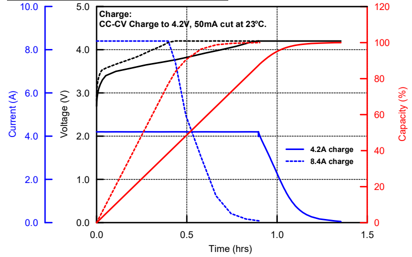


Shape	Cylindrical
Can	Steel
Diameter	21.7 mm (Max)
Height	70.2 mm (Max)
Weight	70 g (Max)

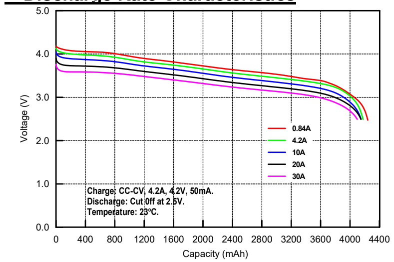
The information contained herein is for reference only and does not imply a performance guarantee or a product warranty. Specifications and characteristics are subject to change without prior notice.

For application specific information, please contact E-One Moli Energy Sales and Applications or the nearest MOLICEL® recognized agent.

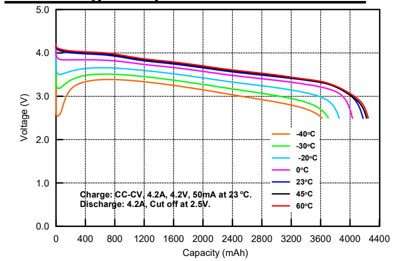
■ Charge Characteristics



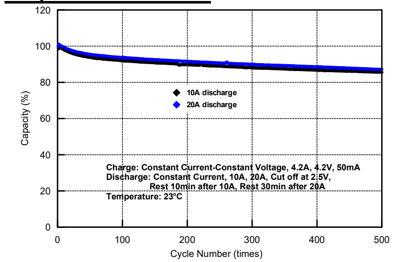
■ Discharge Rate Characteristics



■ Discharge Temperature Characteristics



■ Cycle Characteristics



■ **Taiwan Facility**
10 Dali 2nd Rd., Shan-Hwa,
Tainan City, Taiwan, R.O.C.
Tel: 886-6-505-0666
Fax: 886-6-505-0777
mailto:service@molicel.com
http://www.molicel.com

■ **Canada Facility**
20 000 Stewart Crescent
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Fax: 1-604-466-6600
mailto:molicel@molicel.com
http://www.molicel.com

■ **Headquarters**
10F, 113, Sec.2, Zhung Shan N Rd.,
Taipei, Taiwan, R.O.C.
Tel: 886-2-2567-3500
Fax: 886-2-2567-6500

C) Evaluation procedure

- Welcome to the user test thank you for your participation.

First, I would like to request you sing this subject consent form

- Explain the product using this tex

t:
Kelvin is a home battery pack for solar-powered heating.
It is designed to maximize the energy usage of your solar panels while providing a new heating solution. It transforms the way you warm yourself inside your home.
Conventional heating methods are responsible for roughly 80% of household energy usage. Kelvin addresses this problem by offering three portable heating modules that utilize infrared heating panels. By using infrared radiation, Kelvin provides localized heating, directing warmth directly onto your body instead of heating the surrounding air around you. This method not only offers greater efficiency but also delivers a more comfortable and enjoyable heating experience.
The flexibility of Kelvin allows you to take the warmth wherever you go, both inside and outside your home. The portable heating modules provide a convenient heating solution that adapts to the user's needs. No longer bound by fixed heating systems, Kelvin allows you to create a comfortable environment anywhere you go.
By using battery power, the heating modules encourage users to become more conscious of their energy consumption. With a finite amount of energy stored, users develop a heightened awareness of the energy they use.
Furthermore, the warm light emitted by the heating modules adds to an ambiance and coziness to your surroundings. This warm illumination enhances the overall experience, making the user feel more comfortable.
With Kelvin, you can optimize the use of your solar panels and enjoy the comforts of efficient and localized heating. Kelvin improves the way people stay warm while reducing their carbon footprint.

- Ask to interact with the product and explain all their thoughts out loud.

- After the first walkthrough of the product:

Scenario 1:
It is wintertime and freezing outside. after dinner you go to your room in the attic to play some video games. since your room is not that well isolated, the room is only 14C when you come in. You decide to go back and grab a heater from Kelvin. Rein act the rest of the scenario

Scenario 2:
In is a rainy cold day in the fall. everyone from your household is home and you decide to watch a movie together in the living room. It is only 17,5C in the living room though so you decide to get some heating from a Kelvin stack. Rein act the rest of the scenario

Scenario 3:
It is February and it is your birthday. the entire day there will be people over celebrating your birthday. In the morning your grandparents and some other elderly people come by. In the afternoon however is the big party where the rest of your friends and family come to party. You want to have your home sufficiently heated for the elderly but also have enough heating energy stored for the party in the afternoon. Rein act the rest of the scenario

- Open discussion about the design, what the ideas behind it were.

- End of user evaluation, thanks for the participation!

D) Subject consent form

Toestemmingsformulier proefpersoon

- Ik heb informatie gekregen en ik begrijp waar dit onderzoek over gaat. Ook kon ik vragen stellen. Mijn vragen zijn voldoende beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.
- Ik weet dat meedoen vrijwillig is. Ook weet ik dat ik op ieder moment kan beslissen om toch niet mee te doen of te stoppen met het onderzoek. Daarvoor hoef ik geen reden te geven.
- Ik weet dat sommige mensen mijn gegevens kunnen inzien. Die mensen zijn Luc Buijtels en betrokken project coaches van de TU/e.
- Ik geef toestemming voor het verzamelen en gebruiken van mijn gegevens voor wetenschappelijke publicaties en meer of ander onderzoek op mijn gegevens. Wel zullen deze anoniem verwerkt worden in de artikelen.
- Ik geef toestemming om mijn gegevens op de onderzoekslocatie nog [5] jaar na dit onderzoek te bewaren.

Ik wil meedoen aan dit onderzoek.

Naam proefpersoon:
Handtekening: Datum : __ / __ / __

Ik verklaar dat ik deze proefpersoon volledig heb geïnformeerd over het genoemde onderzoek.

Als er tijdens het onderzoek informatie bekend wordt die de toestemming van de proefpersoon zou kunnen beïnvloeden, dan breng ik hem/haar daarvan tijdig op de hoogte.

Naam onderzoeker (of diens vertegenwoordiger):
Handtekening: Datum: __ / __ / __

De proefpersoon krijgt een kopie van het getekende toestemmingsformulier.

E) Transcripts user tests

P1 Notes
The design looks nice, it is a big box and I don't have much comments on that. The white colors are nice, good neutral colors for inside my home. My home has a lot of plastered and painted white walls so it think it would fit nice. Easy to fint in a modern home, not so much in an old home
The product would be a great addition to my solar panels. I just got them and they give quite some power. Sometimes I go into the meterkast and look at the electricity meter, it if fun to see it turning backward but that means that I am losing electricity
As for the module itself. Nice handle and know to turn. Not much furter interactions possible that I see at least. You hev the lights which I think would indicate some sort of charge level I think,
Ill just grab the one with full green lights, I think that one is charged the most. It lifts out easily not any real trouble with that.
The black looks good as well, does blend in nice with the rest of the house and is does not stand out that much.
Lets say I want to watch tv on the couch, I can bring it with meee. I do have to find a good place to set it up though.
Does the thing get warm? No not really, it could get warm a little bit, would it change they way you act with it?
Well it would as im am putting it netxt to me on the coch but if that thing gets hot I maybe don't want to put it on my couch or something.
As for turning it oin, just a twist of the nkob and some nice heat would come of is suspect.
What doe the light doe?
Warm light makes people feel warmer and more coziy, juslt like a fireplace
I am not sure these orange lights will have the same effect on me
What can I comparer the heat to doe you know?
The heat is a bit like a terrace heater.
Just like the one we have in the eeeuuh serre?
Yess a bit like that.
I always like that heat. When it is fall ,or winter and we sit in the serre, I like it when that thing is on, when you sit in front of it it really gives of some nice warmth unlike any other really. if it feels the same as a radiant terrace heater, I really like the idea
I know that radiant heaters can really give you a nice warm feeling when you are close to one
Nice so lets move onto the scenarios:
1: yeah I would use it any other than just now, bring tit wit hem and turn on
Concerned about battery?
i mean not really, how long can it heat?
6 hours
No problem at all
Scenario 2 I would like to turn one unit on at the couch were im watching tv just to have a small bit of het. I might not even use it and just use a blanket or a sweater.
For scenario three it would be a bit more difficult. Id have them fully charged the day before so might be a bit cold the day before. On the day having 6 plus 6 plus 3 hours would be plenty. Big group ofg people generate heat themselves so in afternoon not necessary anymore
needing to plan for the entire day home with a lot of people requires some thought

Explanation about design and reasoning ……………………………..
Oh il like the link to a fireplace. Use one quite often in the winter, really nice and worm feeling does it give me. Knowing to chop all that wood causes a late of time,
You do really mis that nowadays do you
Having such a limit on the battery may actually help me plan out my energy usage a bit better just like I need plan out how much wood I will bring in for an evening. I really hate it that I have to go outside again I f I do not have enough wood for the evening
Any cool ideas on how to improve it
If you want to make people more conscious like carrying in wood, wood Is quite have, if you could somehow make the module lighter if there is less energy inside than you could actually feel a bit of what you are using and such

P2 Notes

Just start with the looks, then start touching and using.
Well it looks nice although a bit blocky for *old people* they often like the more sophisticated and complex things of the past
Everything is so blocky and simple nowadays. Houses, iPad, cars, you name it
That's not something I really like.
The colors also would not really fit in my old house, but again these are things for modern houses, not my old home
What are those lights?
They indicate how much charge there is in a module
Oh soo green and more lights is full, and orange a bit full, and the last one is empty then
Well I don't like that they are constantly shinning bright in my eyes they are definitely to bright for my old eyes.
Lests just grab a module okay?
PFFFFFFFFFFFF ooouugh it's a bit heavy for me.
Now it doesn't even have batteries
For an old lady like me that could definitely be a problem if they are full with batteries, I don't think I could lift it then. Now I do already have to carry it around the house with my stroller.
Maybe just have the batteries gone and a simple power cord
Or you are a clever boy, cant you think of a super light battery
I do like the local heat, also an old lady living alone in such a big house, heating the entire house and all of its rooms just for me is such a waste, then I really like this better
How much do you think about the energy you use?
I don't really think of it, the thermostat is on the same temperature and it just heats up if its cold.
With a box I would also just turn it on not really thinking about it
But the impact it would have on my heating bill would definitely help. As an lonely and only person in this house just having the heat wherever I go can save some time
Having a comfortable temperature all around you is also nice, but this radiant heat feel also really good

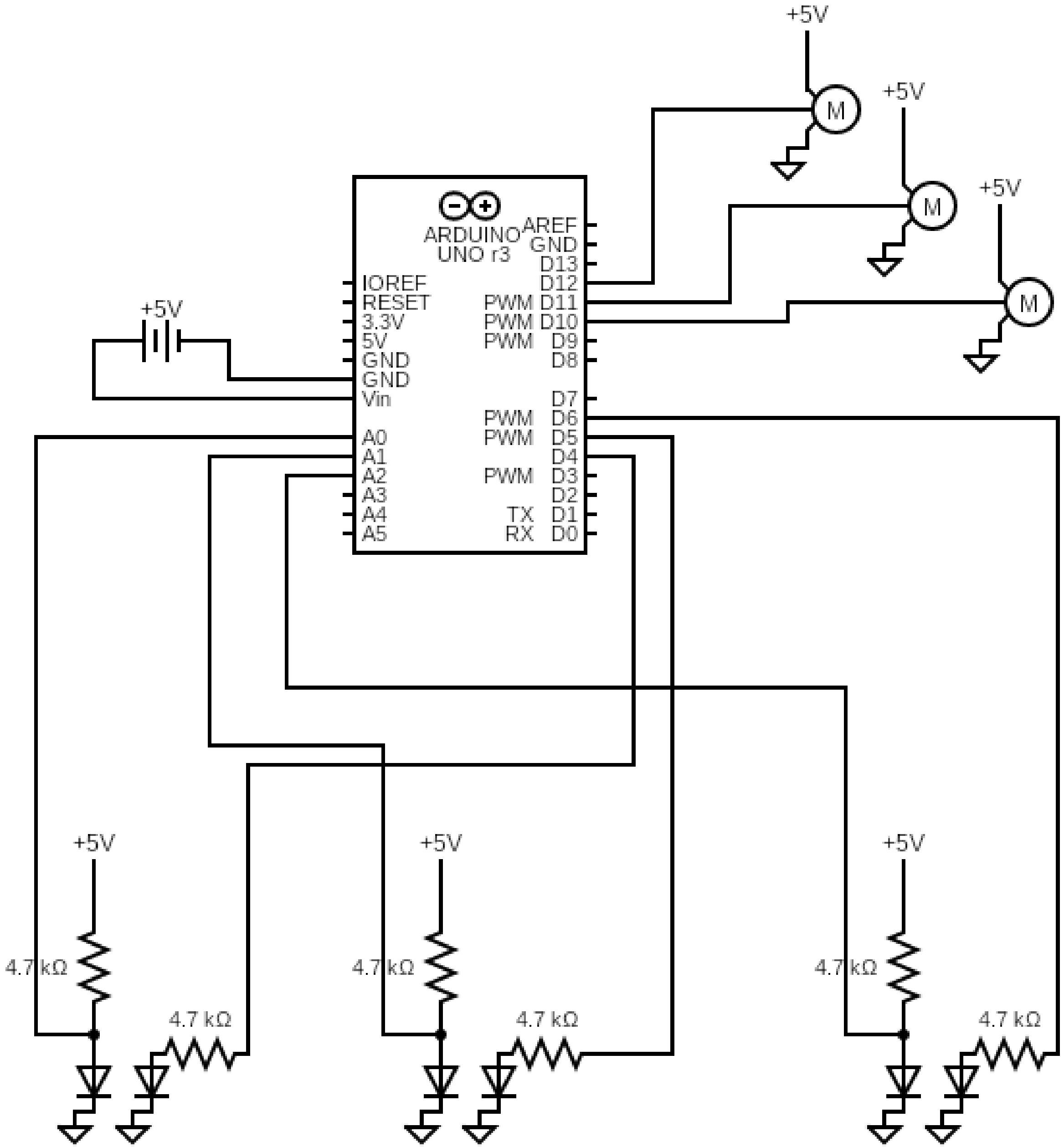
Scene 1:
Well I wouldt reaalyknow as I cant walk up stair anymore so I am not goin to the attic any time soon
Well we'll try scenario 3 then
Having people over I would put all of them on the table so they can grab one ifg they want.
Or I have one then heats up all of us at one

Explanation about design and reasoning ……………………………..
the light is a nice touch however It is just not the same as a real fire
a long time ago grandpa used to make a fire sometimes and I do rememr the feeling
I lik the idea of bring a fire back to modern houses, maybe just carry around a box with actual fire in at. Let it burn on gas like our new fireplace,
Well I say new but that's probably older than you so not that new anymore hahaha
Well as an old lady I feel like this wouldn't really fit me or my house but then again it is designed for houses way in the future
I don't think I will be able to help you improve with technology, youll probably have to do that yourself
No by giving all your insights just using and talking you definitely helped my, don't worry
P3 Notes
Where do I start
Lets just start of with the looks
The design is attractive. For the interior of my house, the white colors are wonderful, good neutral colors. It would probably suit well because the majority of the walls in my house are painted and plastered white. In a modern home, finding things is simple; in an older home, not so much.
I can bring it to my garage or outside on the table with me if, for example.
not as sophisticated as some old-school fireplaces, they something have the nice curves and meatal bits and such
I'll just take the one that has all of the green lights because I believe it to be fully charged. There is no significant difficulty in lifting it out.
Wow, A bit heavy for me if full with bateries
Additionally, the black does not stand out all that much
Regarding the actual module. nice grip, turns well. There aren't many more interactions that I can see, at least. You have the lights, which I believe signify some sort of charge level
Realy simple interactions. very selfexplainatory

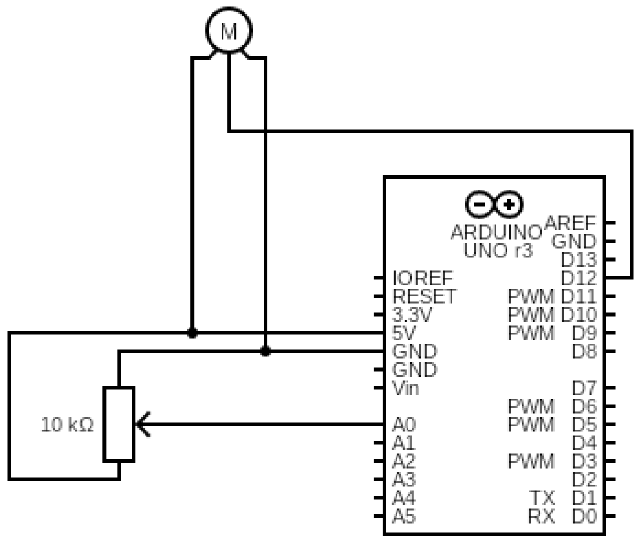
When using it it does keep people together, me and the whole family just sitting around this thing.
I don't know hot warm it can be but hopefullyit gets really hot for that nice and cozy feeling
even if you house is warm, when it is cold outside you somethimes just have these cold moments, I suspect with Klevin this will not be the case
You said it is also about making you more aware of your energy usage?
Yes, by having a finite amount people will have to think about how they will spend it
Having Kelvin doesn't directly make me more aware or I'll have to experience it for real. It is hard to judge if you cant really use it for an extended period of time with a working product
Would you feel more sustainable?
Well yess because it would definitely help my solar panels, but I did not realay know that they would give extra energy, I thought they would just give energy when people needed energy.
Now Kelvin can be that energy when the sun is shining.
Aaaaaah I get it, well it definitely does make me feel a bit better but aren't batteries bad for the environment with production and such? And when the are broken, the cant really be recycled as well
Scenario 1:
Well ill just grab one and go upstairs to heat up, turn it on fully and then how long can it heat?
6 hours approximately
That should be plenty for me
Scenario 2, ill jet grab one some me and my wife can warm up tighter, she always like that when we do that in front of the fireplace.
Scenario 3:
Well we are already with many people so we will probably have to be careful with how much energy we use, otherwise e we will not have enough probably, this is again difficult to judge right now, ill need an extended time to test this out

Explanation about design and reasoning ………………………………..
Oh the way you tell it right now is really interesting, I did not think about it that way
What a good idea, well ill hope it works out for you

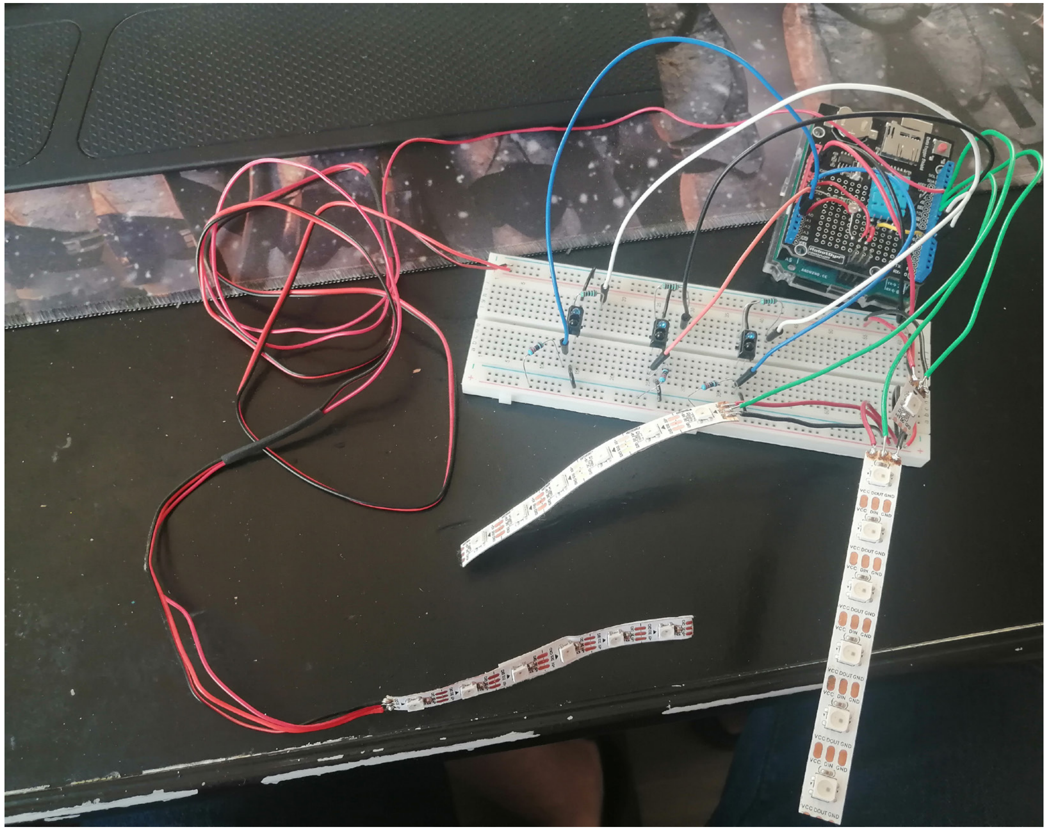
F) Arduino schematics

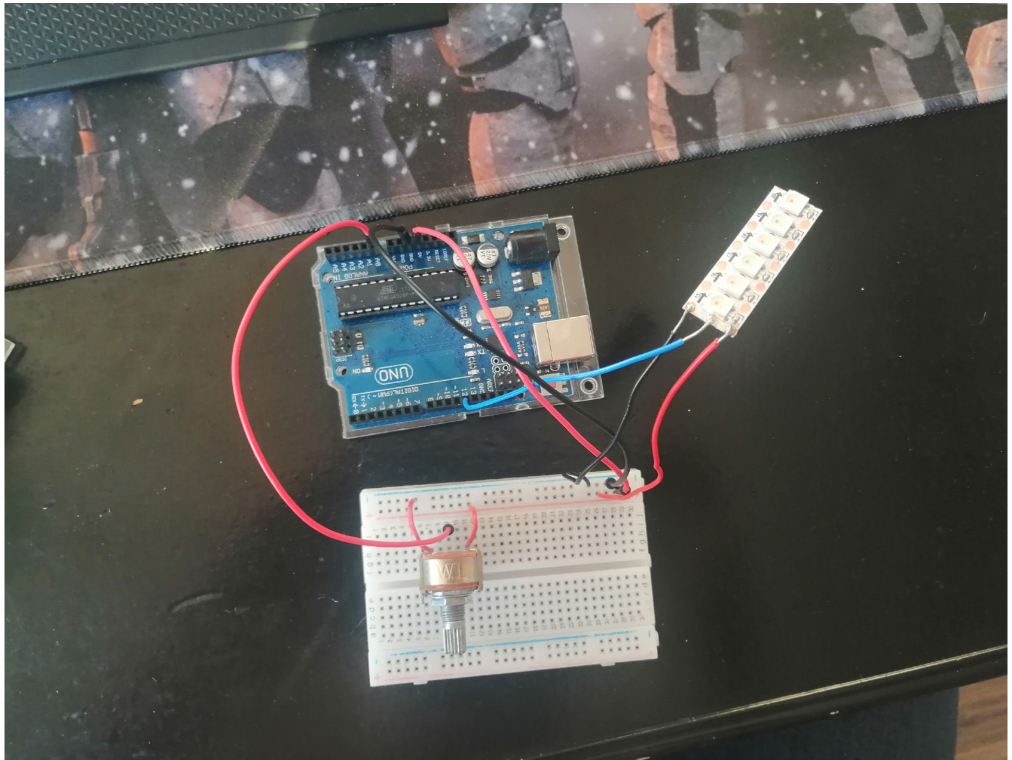


M = Ledstrip



G) Arduino prototpyes





H) Processing code with OOCSI

```
import processing.serial.*;
import nl.tue.id.oocsi.*;

Serial port;  // Create object from Serial class
String LDR_Value;     // Data received from the serial port
int HOME_COMING = 0;

agentType myIdentity = agentType.EH_LDR;
OOCSI oocsi;

class HomeComing {
  void handleMessages(OOCSIEvent event) {
    for (messageType type : messageType.values()) {
      if (event.has(type.name())) {
        HOME_COMING = event.getInt(type.name(), 0);
      }
    }
  }
}

HomeComing GH_HomeComing;

void setup()
{
  port = new Serial(this, "COM3", 9600);
  oocsi = new OOCSI(this, myIdentity.name(), "oocsi.id.tue.nl");
  GH_HomeComing = new HomeComing();
}

void draw()
{
```

```
  if ( port.available() > 0)
  {  // If data is available,
    LDR_Value = port.readStringUntil('\n');        // read it and store it in val
  }
  //println(LDR_Value); //print it out in the console

  oocsi
    .channel(agentType.SS_ChickenCoop.name())
    .data(messageType.EH_EnergyFromSolarPanel.name(), LDR_Value)
    .send();

  delay(1000);
}

void handleOOCSIEvent(OOCSIEvent GoodHome) {

  GH_HomeComing.handleMessages(GoodHome);

  if (GoodHome.getSender().equals(agentType.GREETME.name())) {
    println(HOME_COMING);
  }
}
```

I) Arduino code with OOCSI

```
//Final Bachelor Project, TU/e Q3+4, 2022-2023
//Luc Buijtels 1330071
//
//This is the code for my final bachelor project

#include "DHT.h"               //Import DHT library
#include "Adafruit_NeoPixel.h"  //Import Adafruit Neopixel library

#define DHTPIN 7      //Digital pin connected to the DHT sensor
#define DHTTYPE DHT11  //DHT 11

int LEDCOUNT1 = 6;  //amount of RGB leds in the strip
int LEDPIN1 = 12;   //digital pin the led strip is connected to
int LEDCOUNT2 = 6;  //amount of RGB leds in the strip
int LEDPIN2 = 11;   //digital pin the led strip is connected to
int LEDCOUNT3 = 6;  //amount of RGB leds in the strip
int LEDPIN3 = 10;   //digital pin the led strip is connected to
int LEDCOUNT4 = 1;  //amount of RGB leds in the strip
int LEDPIN4 = 9;    //digital pin the led strip is connected to

int LDR_Pin = A0;  //LDR sensor on Analog pin 0
int DS1 = A1;
int DS2 = A2;
int DS3 = A3;
int LED_Pin = 13;  //LED on Digital pin 13


int LDR_Value = 0;             //Set initial value for LDR output
int GoodHome = 0;               //Set the intitial value for the incomming data from the good home project
float Temp = 0;                //Set initial value for temperature
int a, b, c, d, e, f, g, h, i;  //Set intergers for the reading and filtering of distance sensor
```

```
Adafruit_NeoPixel pixels1 = Adafruit_NeoPixel(LEDCOUNT1, LEDPIN1, NEO_GRB + NEO_KHZ800);  //defines library
Adafruit_NeoPixel pixels2 = Adafruit_NeoPixel(LEDCOUNT2, LEDPIN2, NEO_GRB + NEO_KHZ800);  //defines library
Adafruit_NeoPixel pixels3 = Adafruit_NeoPixel(LEDCOUNT3, LEDPIN3, NEO_GRB + NEO_KHZ800);  //defines library
Adafruit_NeoPixel pixels4 = Adafruit_NeoPixel(LEDCOUNT4, LEDPIN4, NEO_GRB + NEO_KHZ800);  //defines library

DHT dht(DHTPIN, DHTTYPE);  //defines library

void setup() {
  Serial.begin(9600);  //Set the baud rate of the serial port to 9600
  dht.begin();         //Initialize DHT library
  pixels1.begin();     //Initialize the NeoPixel library.
  pixels2.begin();
  pixels3.begin();
  pixels4.begin();

  pixels1.clear();  //Clear all the pixels
  pixels1.show();   //Update all the pixels
  pixels2.clear();
  pixels2.show();
  pixels3.clear();
  pixels3.show();
  pixels4.clear();
  pixels4.show();

  pinMode(LED_Pin, OUTPUT);  //Set LED as output
  pinMode(LDR_Pin, INPUT);   //Set LDR as input
  pinMode(4, OUTPUT);        //Set pin 6 as output
  pinMode(5, OUTPUT);        //Set pin 6 as output
  pinMode(6, OUTPUT);        //Set pin 6 as output
}

void loop() {
  LDR_Value = analogRead(LDR_Pin);  //Read out LDR value
  Temp = dht.readTemperature();

  /////////////////////////////////////////Debug code
```

```
// Serial.println("Light level: ");
Serial.println(LDR_Value);  // Prints the LDR value in the serial COM port
// Serial.println("Temperature: ");
// Serial.println(Temp);
///////////////////////////////////////

if (LDR_Value > 600) {          //If the LDR has a value above 600
  digitalWrite(LED_Pin, HIGH);  //Turn LED on
} else if (LDR_Value < 600) {   //If not
  digitalWrite(LED_Pin, LOW);   //Tirn LED of
}

//////////////////////////////////////////////////////////////DS1
digitalWrite(6, HIGH);   //Turning ON LED
delayMicroseconds(500);  //wait
a = analogRead(DS1);     //take reading from distance sensor(pin A3) :noise+signal
digitalWrite(6, LOW);    //turn Off LED
delayMicroseconds(500);  //wait
b = analogRead(DS1);     //again take reading from photodiode :noise
c = a - b;               //taking differnce:[ (noise+signal)-(noise)] just signal

if (c < -15) {  //If the distance value is below -40
  for (int j = 0; j < 6; j++) {
    pixels1.setPixelColor(j, pixels1.Color(0, 150, 0));
    pixels1.show();  //Update all the pixels
  }
} else if (c > -15) {  //If the distace value is above -40
  pixels1.clear();     //Clear all pixles
  pixels1.show();      //Update all the pixels
}

//////////////////////////////////////////////////////////////DS2
digitalWrite(5, HIGH);   //Turning ON LED
delayMicroseconds(500);  //wait
d = analogRead(DS2);     //take reading from distance sensor(pin A3) :noise+signal
digitalWrite(5, LOW);    //turn Off LED
```

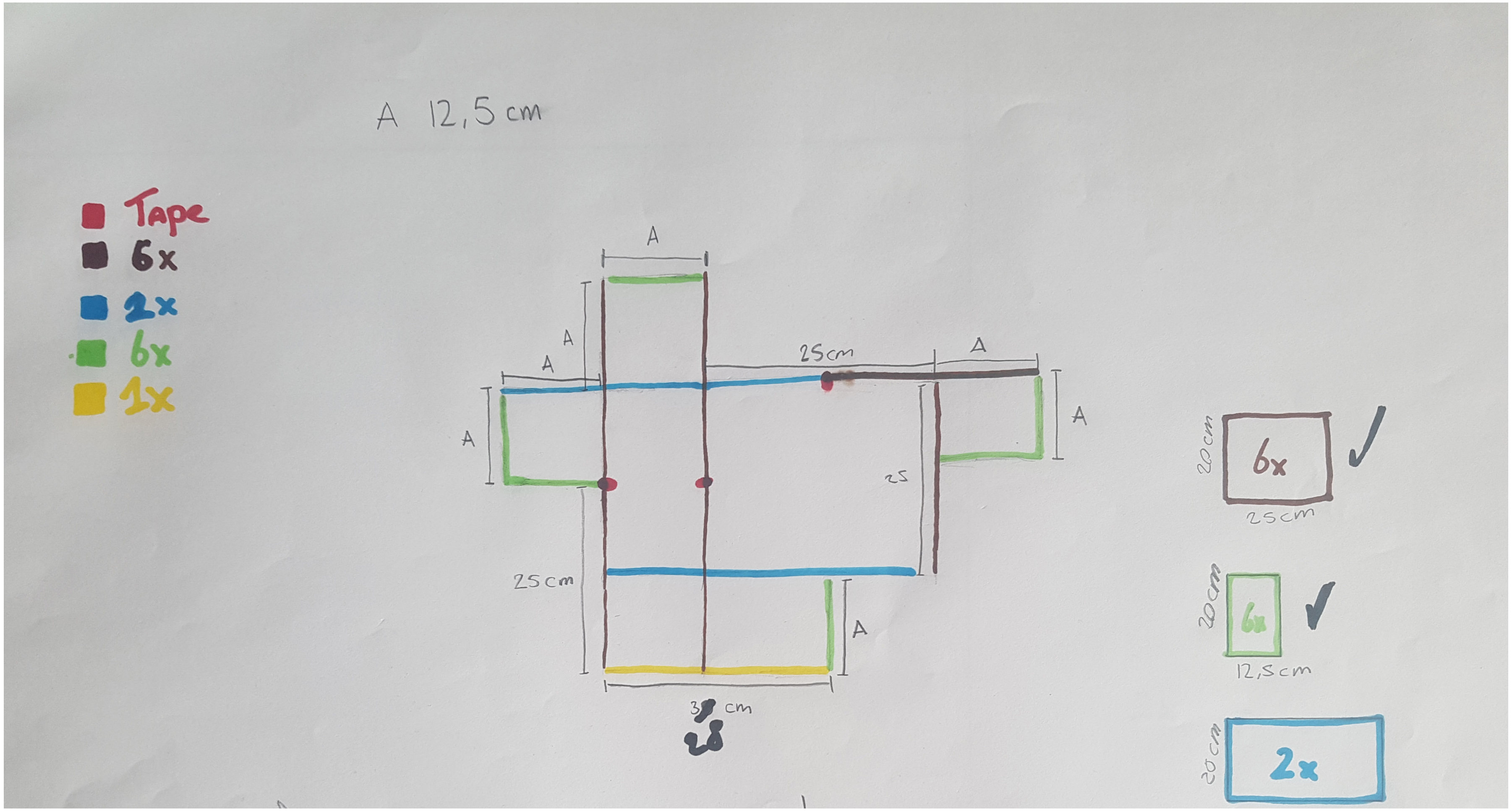
```
delayMicroseconds(500);  //wait
e = analogRead(DS2);     //again take reading from photodiode :noise
f = d - e;               //taking differnce:[ (noise+signal)-(noise)] just signal

if (f < -15) {  //If the distance value is below -40
  for (int k = 0; k < 4; k++) {
    pixels2.setPixelColor(k, pixels2.Color(180, 60, 0));
    pixels2.show();  //Update all the pixels
  }
} else if (f > -15) {  //If the distace value is above -40
  pixels2.clear();     //Clear all pixles
  pixels2.show();      //Update all the pixels
}

///////////////////////////////////////////////////////////////////DS3
digitalWrite(4, HIGH);   //Turning ON LED
delayMicroseconds(500);  //wait
g = analogRead(DS3);     //take reading from distance sensor(pin A3) :noise+signal
digitalWrite(4, LOW);    //turn Off LED
delayMicroseconds(500);  //wait
h = analogRead(DS3);     //again take reading from photodiode :noise
i = g - h;               //taking differnce:[ (noise+signal)-(noise)] just signal

if (i < -15) {  //If the distance value is below -40
  pixels3.setPixelColor(5, pixels3.Color(150, 0, 0));
  pixels3.show();  //Update all the pixels
} else if (i > -15) {  //If the distace value is above -40
  pixels3.clear();     //Clear all pixles
  pixels3.show();      //Update all the pixels
}

//////////////////////////////////////////Debug code
// Serial.println("Distance2: ");
//Serial.println(i);  //denoised signal (c,f,i)
//////////////////////////////////////////
```

```
  if (Serial.available()) {
    GoodHome = Serial.read();
    Serial.println(GoodHome);

    if (GoodHome == 48) {  // 0 so noone is home
      pixels4.clear();
      pixels4.show();
    } else if (GoodHome > 48) {  // 1 so someone is home
      pixels4.setPixelColor(0, pixels4.Color(0, 150, 0));
      pixels4.show();  //Update all the pixels;
    }
  }

  delay(100);  //Wait 1 second
}
```

J) Pictures prototypes


filament


23-3D.nl


A 12,5 cm
Tape
6x
2x
6x
1x
A
A
A
25cm
A
A
A
25
A
25cm
A
cm
28
6x
20cm
25cm
6x
20cm
12,5cm
2x
20cm